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Aeronautical Engineering REVIEW

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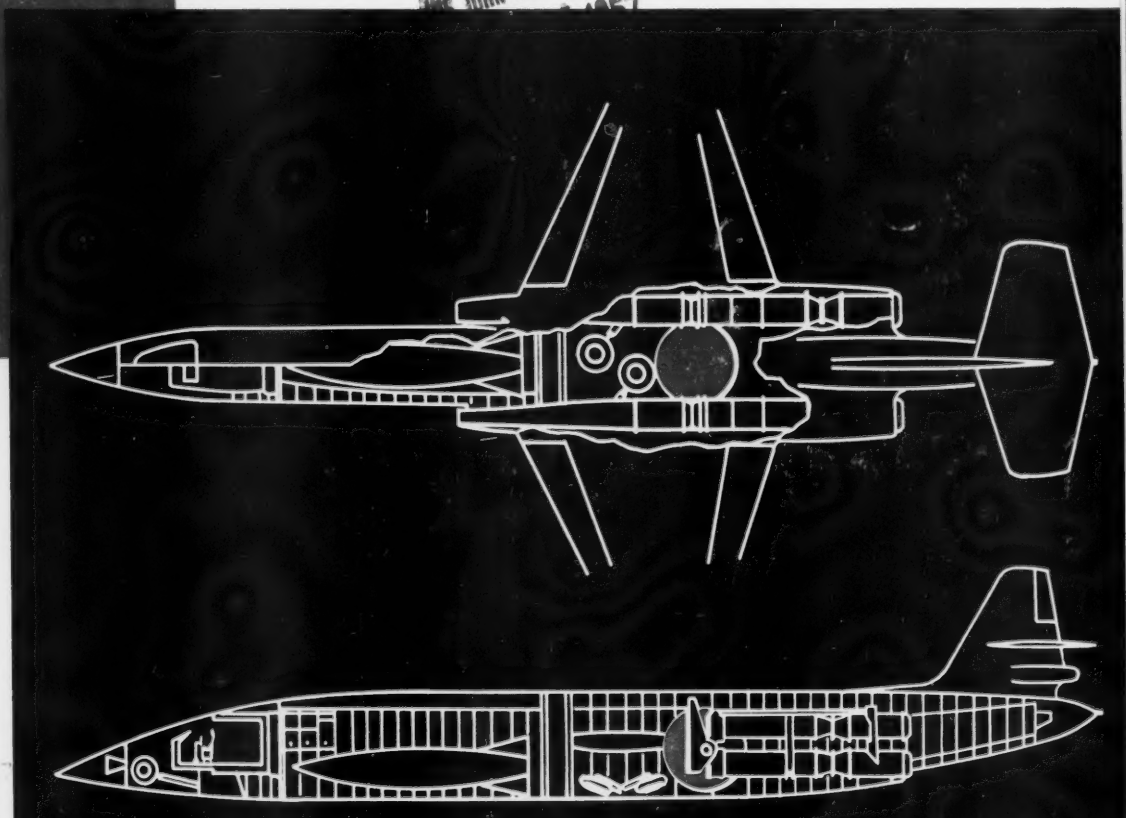


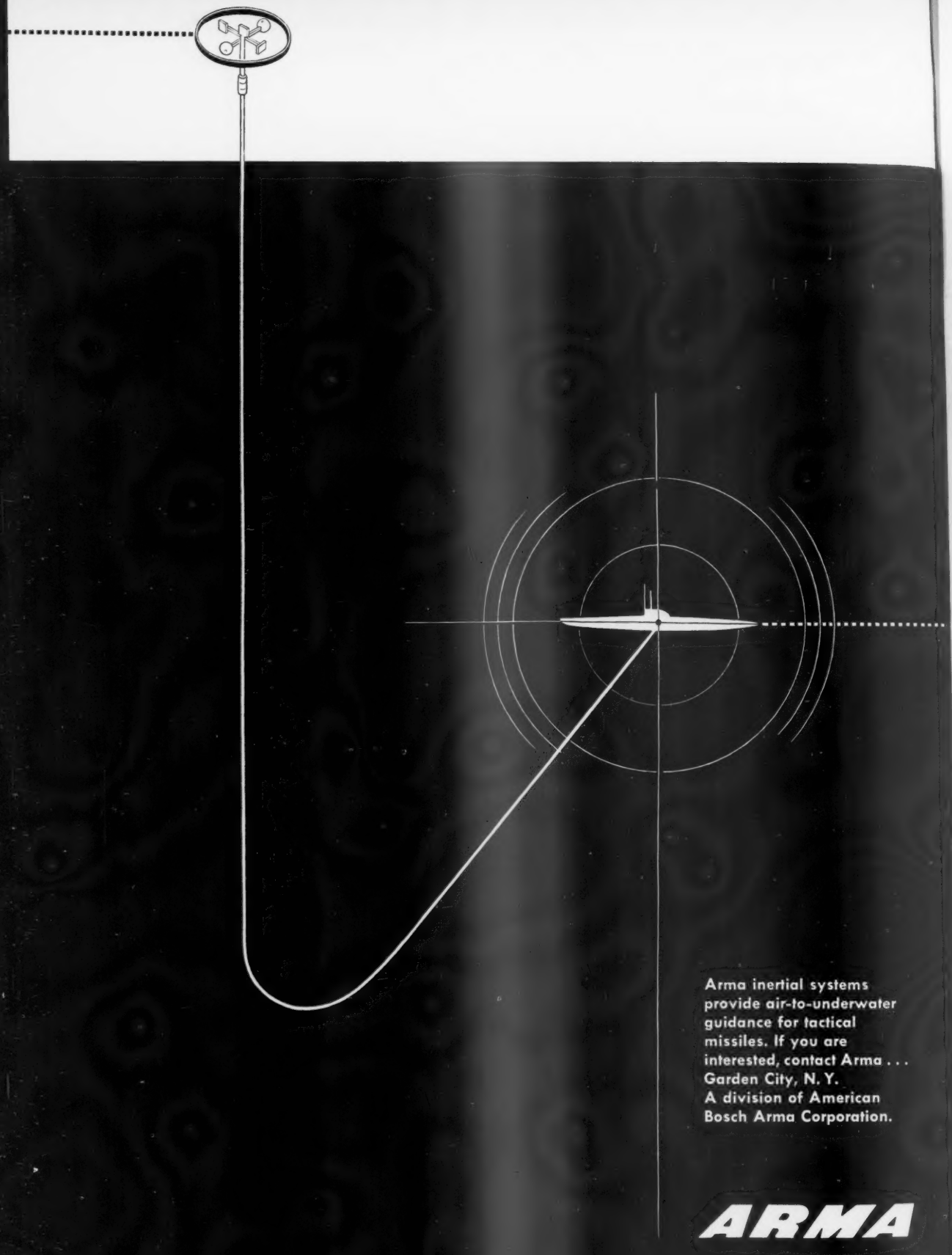
DESIGN OF AIR FRAMES FOR NUCLEAR POWER

By Clarence L. Johnson and F. A. Cleveland

our Atomic future

. . . an editorial by J. Carlton Ward, Jr.

June, 1957



Arma inertial systems provide air-to-underwater guidance for tactical missiles. If you are interested, contact Arma . . . Garden City, N. Y. A division of American Bosch Arma Corporation.

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SPAWNING GROUND

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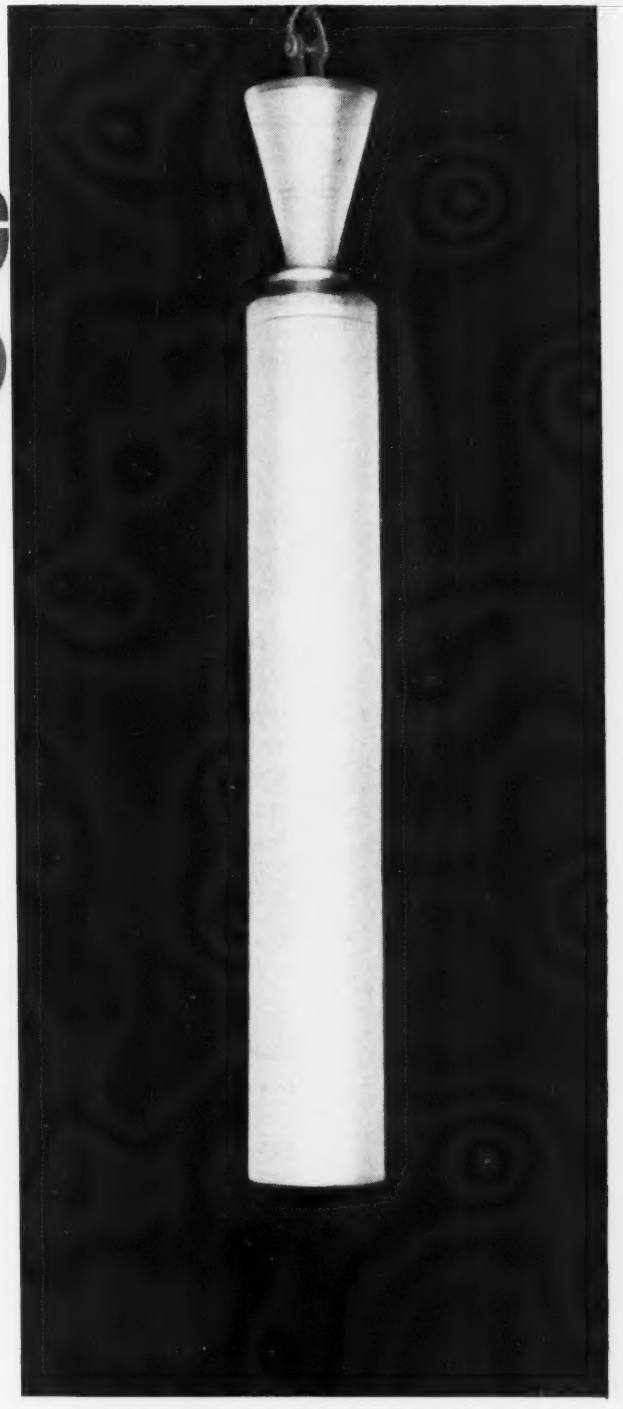

By the time you read this message, the large rocket motor case shown here—white-hot from heat treating—will be standing ready, loaded with solid propellant, poised to rush a guided missile skyward.

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(2) Goodyear Aircraft maintains one of the largest facilities available in this country for this exacting production. And these facilities are currently completing a huge expansion.

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Aeronautical Engineering Review

Vol. 16—No. 6 June, 1957

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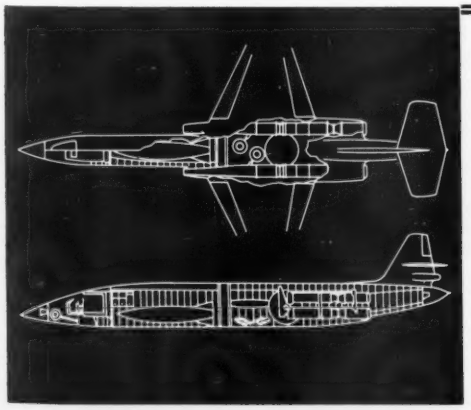

Cover—With this issue, the *Review* presents the first comprehensive study of problems that air-frame designers must solve before the first nuclear-powered airplane becomes a reality. The cover illustrates one of the figures in this remarkable contribution by Clarence L. Johnson, a Fellow, and F. A. Cleveland, an Associate Fellow of the Institute. To read about this challenge by the atom, turn to page 48. For "Our Atomic Future," see the Guest Editorial, page 44.

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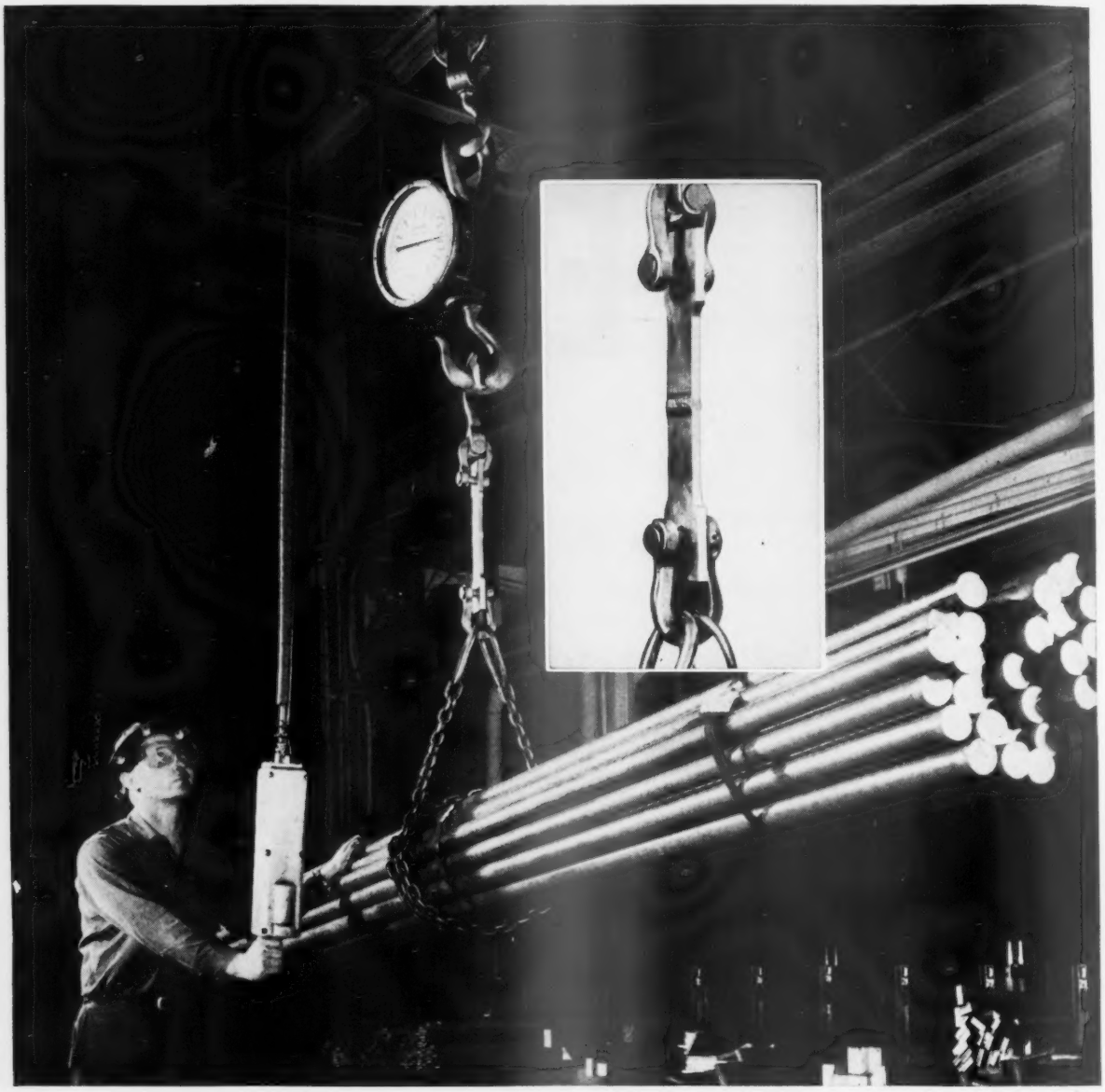

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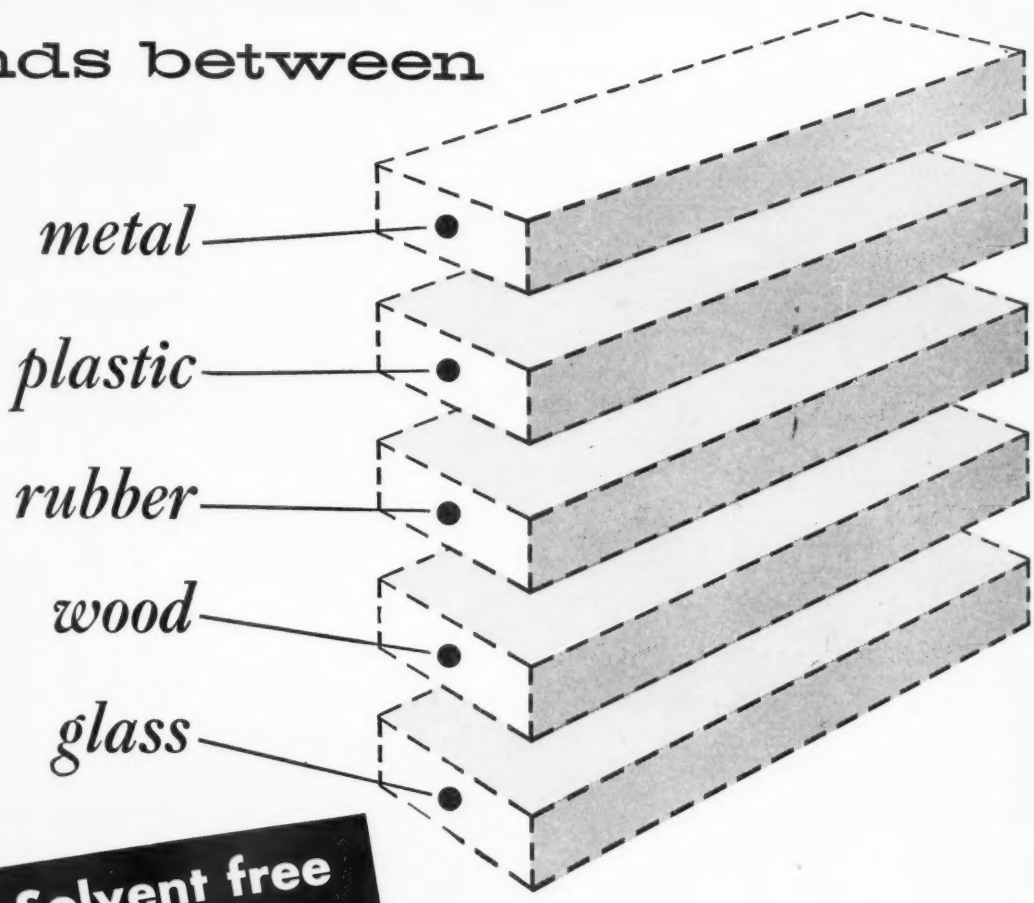

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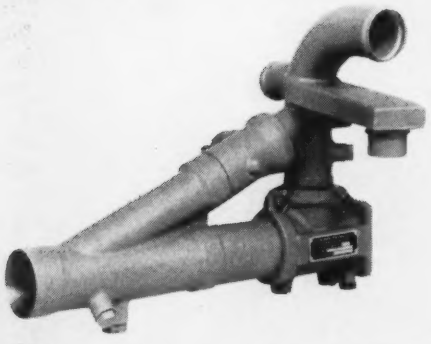

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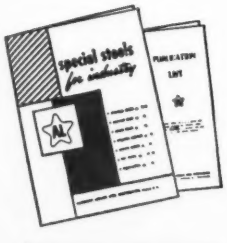

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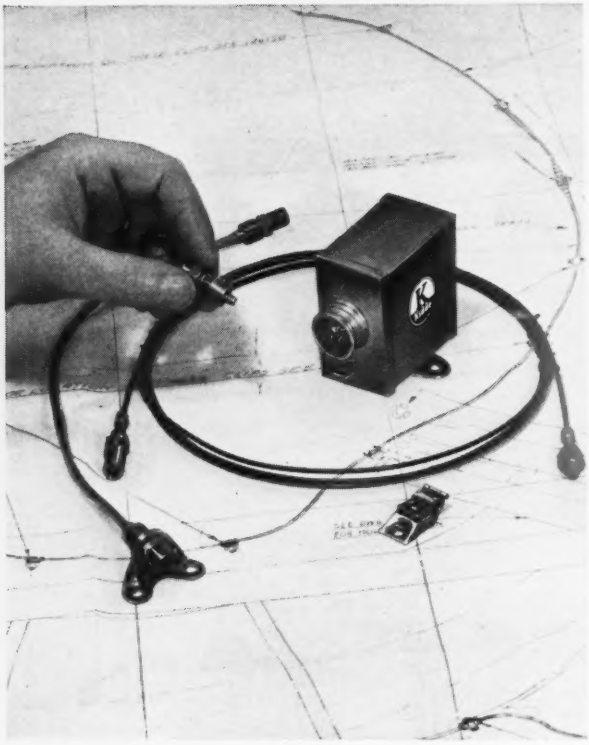

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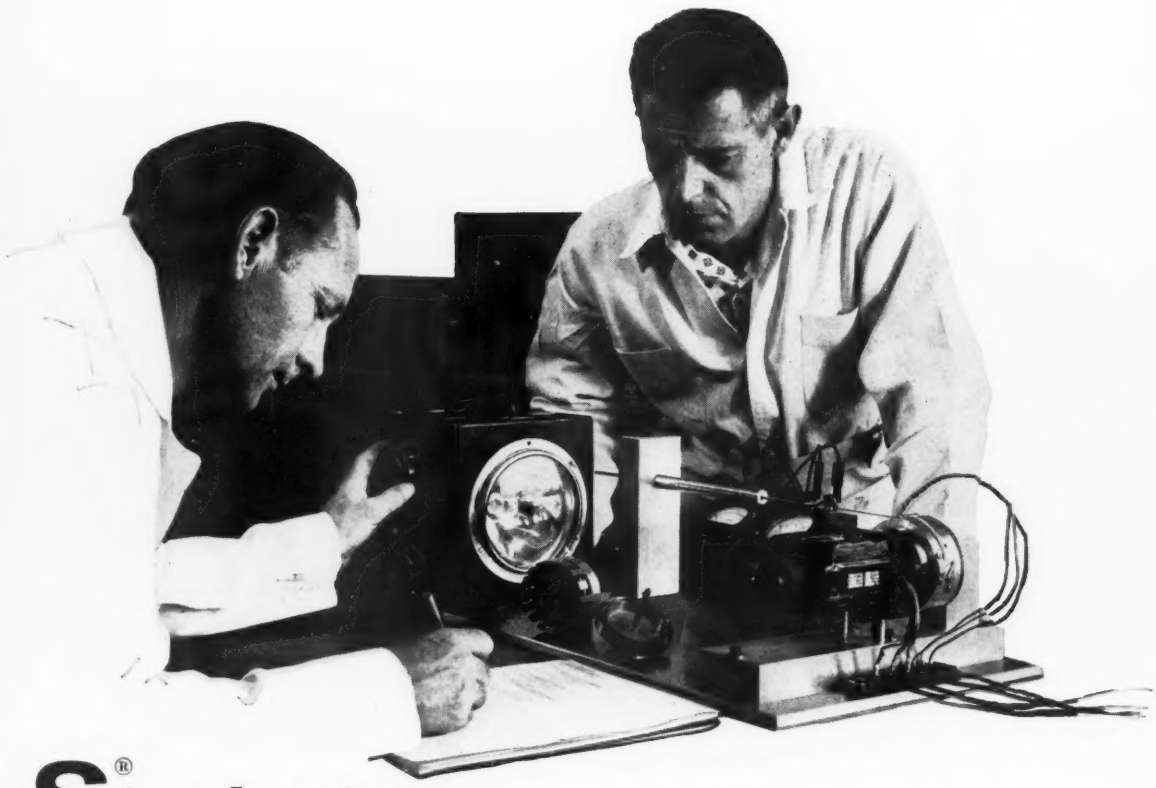

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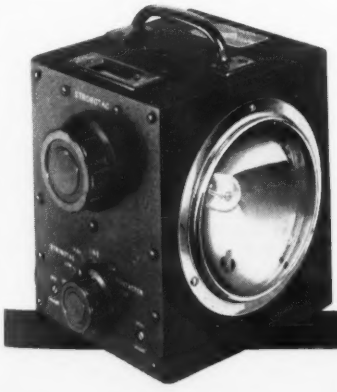

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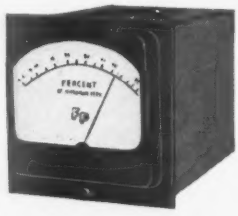

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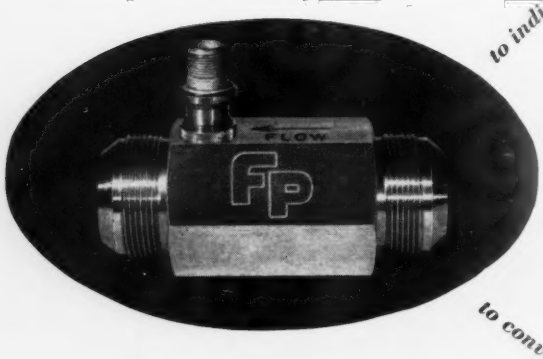
to indicate flow

to indicate steady state flow condition

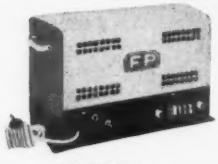
IN-LINE DIGITAL INDICATOR



to totalize flow for batch processes

DIGITAL TOTALIZER

to convert transient flow for analog output



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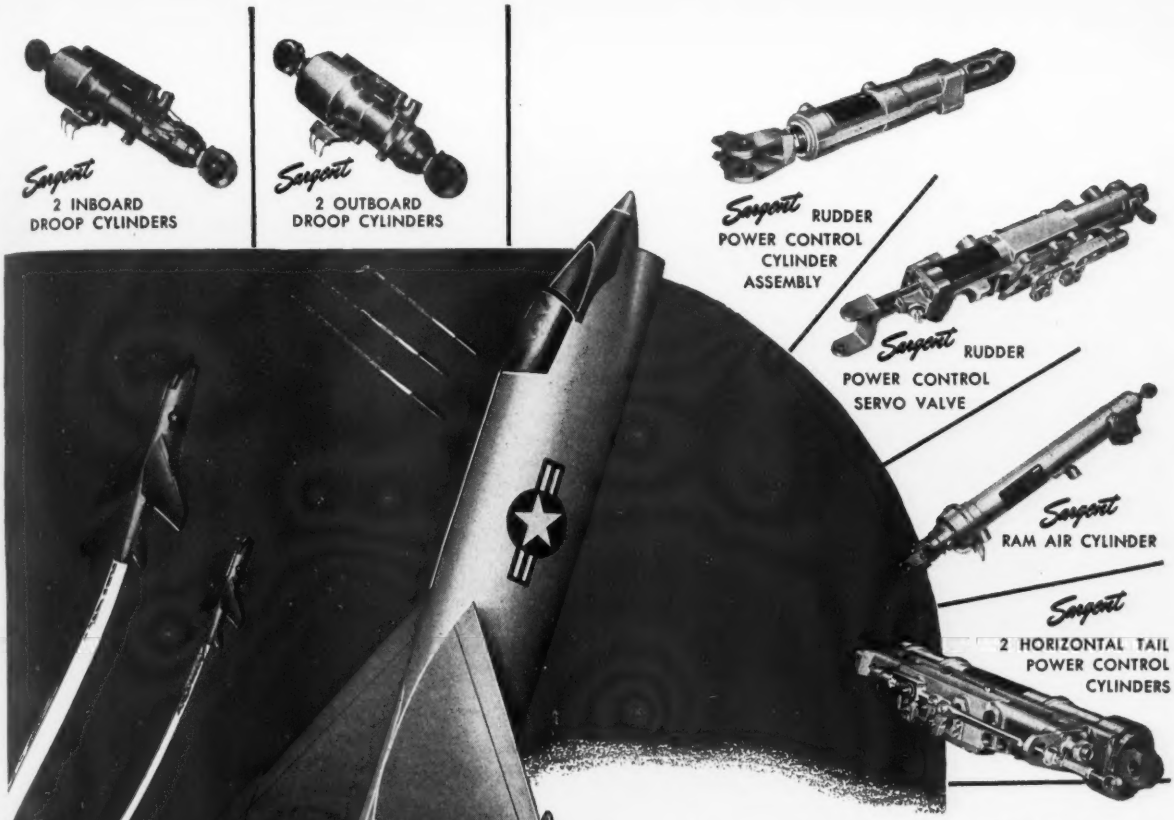

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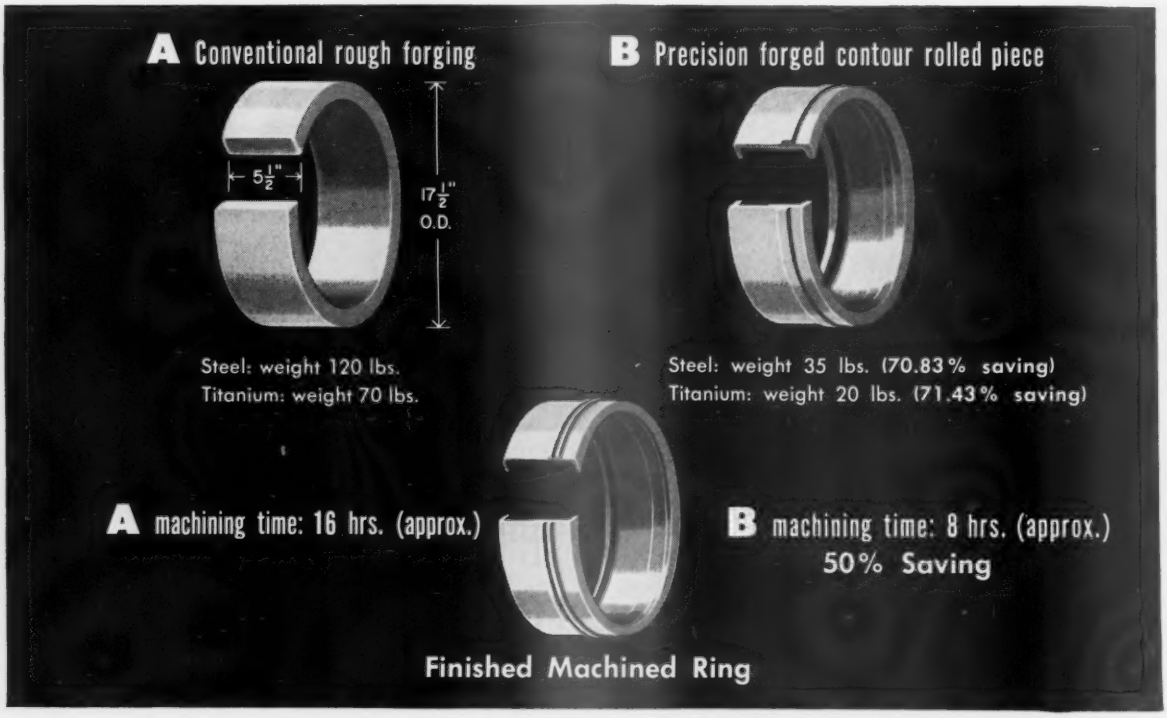
A Conventional rough forging
5½"
17½" O.D.
Steel: weight 120 lbs.
Titanium: weight 70 lbs.
B Precision forged contour rolled piece
Steel: weight 35 lbs. (70.83% saving)
Titanium: weight 20 lbs. (71.43% saving)
A machining time: 16 hrs. (approx.)
B machining time: 8 hrs. (approx.)
50% Saving
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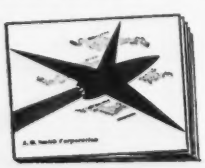

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EEMCO 400 cycle linear actuator **Type D-818** is being installed as a leading edge flap actuator in the latest and fastest supersonic fighter aircraft now being produced for the U. S. Air Force.

Incorporated in the **EEMCO** motor in **Type D-818** is a torque-limiting AC clutch which disconnects the high inertial load imposed by the motor's armature. A brake can be built into this mechanism if **Type D-818** is altered for use in another capacity. Adjustable non-jamming stops are included which are especially convenient when the airplane is being rigged.

One of its outstanding features is that it operates on a frequency range of 320 to 480 cycles, versus a normal range of 380 to 420 cycles. This eliminates need for a constant speed drive for the airplane's generator system, thereby saving maintenance of same as well as considerable cost and weight.

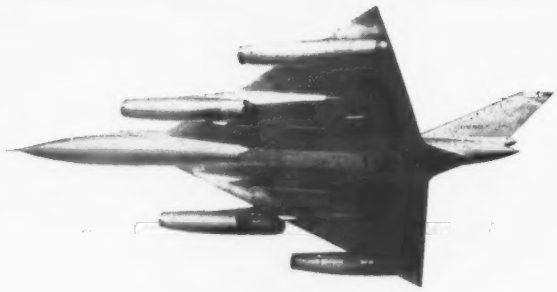
EEMCO is a specialist in the design and production of precision-built actuators and motors. The majority of the latest and fastest aircraft and missiles being produced for the U. S. Department of Defense carry one or more **EEMCO** systems. Industry, too, is using **EEMCO** linear and rotary actuators where precise control of mechanical actuating systems is imperative.

Electrical Engineering and Manufacturing Corp.

4612 West Jefferson Boulevard
Los Angeles 16, California
Telephone REpublic 3-0151

Designers and producers of motors, linear and rotary actuators . . . exclusively!

3-844



MORE AND MORE

MAJOR COMPONENTS

ARE BUILT BY ROHR

For example, brazed, stainless steel, honeycomb panel structures are being manufactured by Rohr for the great new B-58 Hustler, built by Convair for the U. S. Air Force.

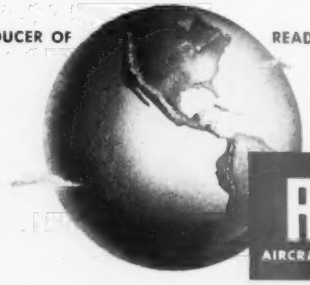
Today Rohr manufactures over 30,000 airplane parts, included in such major components as stabilizers, elevators, fuselage sections, pneumatic system components, high strength weldments, and stainless steel honeycomb sandwich panels.

More and more, leading air-frame manufacturers count on Rohr for design engineering, for conception, development and production of parts to meet modern flight problems. In many cases, Rohr engineering teams are actually assigned to the customer's plant, to work with the manufacturer's engineering staff and bring back a full understanding of requirements to be met.

And, of course, Rohr is well known as the world leader in production of ready-to-install power packages for airplanes – including the Boeing B-52, KC-135, 707, Convair 880, Lockheed Electra Propjet, Super Constellation, C-130, Douglas DC-7 – and many other of America's leading military and commercial planes.

For the aircraft parts you need, next time look to Rohr.

WORLD'S LARGEST PRODUCER OF READY-TO-INSTALL POWER PACKAGES FOR AIRPLANES



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Excellent career openings now for engineers and tooling technicians.

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Hydrazine

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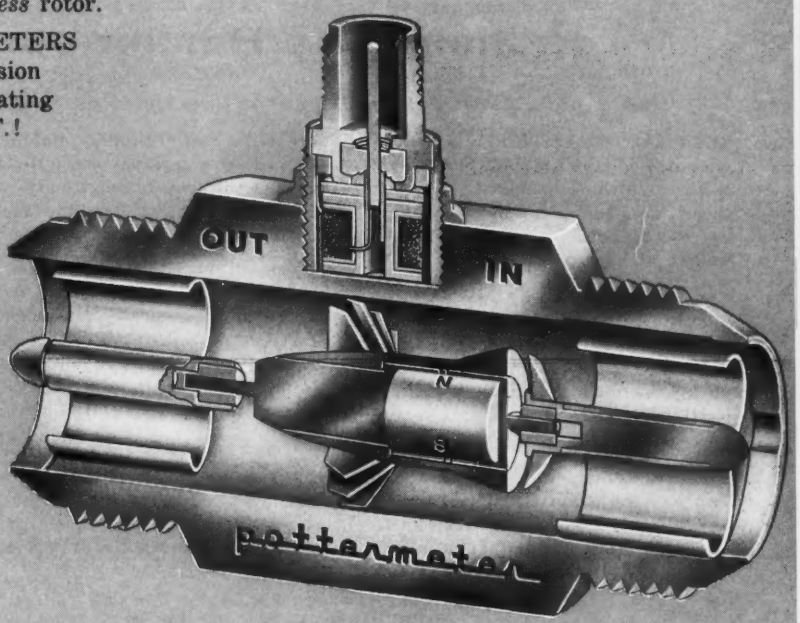
Well blended! Rockets are meticulous drinkers. They like their liquids mixed in precise proportions. That's why in missile and rocket ground testing and airborne telemetering, Potter Electronic Flowmetering Systems have become standard equipment. The POTTERMETER is the only flowmeter which features the hydraulically positioned, *bearingless* rotor.

For more than 15 years, POTTERMETERS have been successfully used for precision measurement of continuous and pulsating flow of fluids from –455°F. to 1000°F.!

Write TODAY for Bulletin A-2



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Progress with **TITANIUM**

HEAT TREATED TITANIUM

...helps the Hustler spread its wings

The Plane: The U.S. Air Force's delta-winged B-58 Hustler, made by Convair—Fort Worth. To achieve supersonic speeds, designers had to make optimum use of all materials, considering strength, weight, high temperature performance.

The Improvement: 6Al-4V titanium alloy, furnished by Mallory-Sharon, was used in certain applications as a direct substitution for steel for wing fittings bearing heavy loads. This alloy, weighing 44% less than steel, has equal or superior strength for the heat-treated conditions.

The Service Need: The Hustler is the first major application of a new technique that extends titanium usefulness—heat treating. The alloy material is supplied in a medium strength level which permits ease of rough machining. Then the part is heat treated and finished machined to the high strengths desired in service.

To help in this development, Mallory-Sharon service engineers recommended and assisted Convair in establishing qualified subcontractor sources. We furnished bar stock to these companies for evaluation, recommended furnace type, conditions, temperatures, and heating times. We performed mechanical and chemical tests before and after heat treatment, to guide this phase of the program to a successful conclusion.

The Result: Improved performance; America's first supersonic bomber. Use Mallory-Sharon's outstanding technical service on *your* applications of this new metal. For information, write Dept. D-5.

MALLORY Ti® SHARON

MALLORY-SHARON TITANIUM CORPORATION • NILES, OHIO

Producers of titanium and titanium alloy sheet, strip, plate, rod, bar, billets

FALSE FACE

Total deception is the special job of **ECM** . . . Electronic Countermeasures. **ECM** tells the enemy where you're *not* and what you're *not*. It fences you from detection, alerts you to trouble. It blinds the enemy, shields you. » » **ECM** plays a disruptive role against all aggressive electronic action, smashes its pattern, draws a red herring across its search paths. » » **ECM** is a sophisticated system of defense designed to protect strategic aircraft at minimum risk. Without **ECM** our weapons systems concept is dangerously modified. With it, the structure of our national defense becomes impregnable. » » In **ECM**, "the silent warfare of deception," LMEE, leading producer of such systems in the free world, contributes another special competence to world peace. Write Dept. E.

LMEE

Aviation Electronics Products Include:

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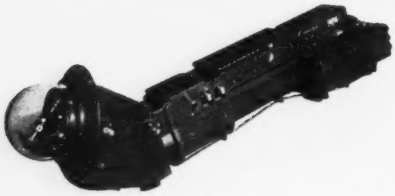
A DEPARTMENT IN THE DEFENSE ELECTRONICS DIVISION

1 B-47 STRATOJET

While building more than 1,500 Y-4 bombsights for B-47 Stratojets, we improved original design, exceeded USAF specifications. Thorough testing at all stages of production assured perfect assemblies. *We delivered on schedule!*



2 B-52

We make Hemisphere Sights for the MD-9 tail defense system in the B-52 Intercontinental bomber. This optical gunsight has a high degree of electronic automation. It calls for exacting manufacturing and environmental testing.

3 B-58 HUSTLER

The B-58 Hustler, the world's first supersonic bomber, carries a series of key assemblies engineered and produced by the Mechanical Division under sub-contract for Emerson Electric Corporation. Military security prevents detailed description of these ultra-precise electro-mechanical units.

CLASSIFIED

These are some of the men, recognized leaders in their fields, who head the integrated departments that team to provide complete systems service.

From the left: Dr. Howard H. Baller (radar and countermeasures, computers); Dr. Cledo Brunetti, Managing Director of Engineering, Research and Development (electronic design, automation); Donald F. Melton (nuclear handling, automation equipment); Dr. John E. Barkley, Director of Research (solid state, infrared); Zeke Soucek (seated), General Manager; Dr. Carl L. Kober, Director of Development (radar, infrared and inertial systems); Harold E. Froehlich (balloons and meteorological systems); Dr. Otmar M. Stuetzer (microwave optics, semi-conductor physics); Dr. Gottfried K. Wehner (behavior of metals in space flight).

3 GOOD REASONS

for investigating our engineering and production capabilities

The top three United States Air Force jet bombers employ bombing or fire control systems produced in part by the Mechanical Division of General Mills.

Our exceptional combination of engineers and technicians, working as a unified team, can start from any stage in aircraft and missile systems and sub-systems: scientific research, development and design, production engineering or precision manufacturing.

Our other immediate activities encompass development and production of guidance systems for missiles, including the Matador II. We are also doing developmental work in underwater ordnance, radar and infrared.

We'd like to tell you more about how we combine conception with completion to provide *complete* service on major assemblies and sub-systems. We're anxious to answer your questions. Write for descriptive literature.

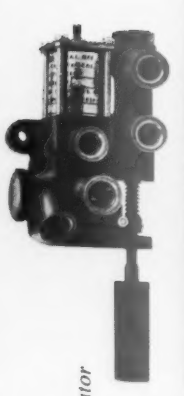
MECHANICAL DIVISION

General Mills

Creative Research and Development • Precision Engineering and Production

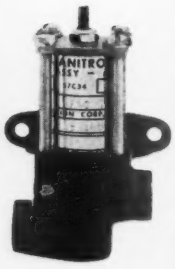
Minneapolis, Minnesota

PNEUMATIC CONTROLS FOR J



1. *Canopy Seal Regulator*

2. *Pylon Tank Regulator*



3. *General Purpose Regulator*

OR **JET AIRCRAFT**

Take air, bled off a jet compressor at extreme conditions of 260 psi and 740°F, reduce to required pressures and deliver it to a canopy seal, a fuel tank, a pneumatic mechanism or an anti-icing system . . .

Solutions to assignments like these call for air pressure controls built with the finest of engineering skills. Janitrol has developed just such skills backed by extensive production facilities in becoming a recognized leader in "harnessing" aircraft combustion and associated equipment. During 50 years of experience in combustion engineering, Janitrol has charted many new regions in related engineering fields including air pressure controls for aircraft.

Here are five, for example, which Janitrol has developed for individual manufacturers of military aircraft:

1—A canopy seal regulator which is mechanically actuated by canopy movement. An auxiliary port is also provided for other uses.

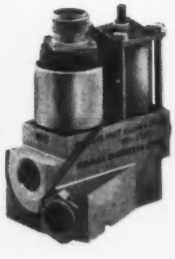
2—Pylon tank regulator with relief valve—maintains constant pressures for fuel transfer.

3—General purpose regulator for canopy seal or is applicable to other uses. Operates with separate solenoid valve for shut-off.

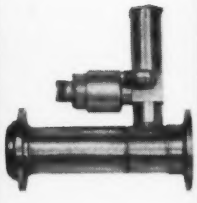
4—Canopy seal regulator with built-in solenoid and relief valve.

5—High pressure regulator used in connection with thermal anti-icing systems where high air flows are required.

We invite you to consult your nearest Janitrol district engineering representative concerning *your* air control problems.



4. *Canopy Seal Regulator*



5. *High Pressure Regulator*

Janitrol

AIRCRAFT-AUTOMOTIVE DIVISION
SURFACE COMBUSTION CORPORATION
Columbus 16, Ohio

DISTRICT ENGINEERING OFFICES: WASHINGTON, D.C., PHILADELPHIA, COLUMBUS, FT. WORTH, HOLLYWOOD

World's largest 'copter...

Rotor hubs of 4340 steel support 16-ton craft carrying 40-man, combat-equipped platoon

Rotor hubs for Vertol Aircraft Corporation's giant whirlybird posed a twofold problem:

First, they had to be strong . . . strong enough to lift over 16 tons including her payload. They needed high shock and fatigue-resistance, too. And they had to be *light*.

Second, because of their complexity, the hubs had to be brought up to uniform strength by heat-treatment prior to machining. Thus a steel was required that would respond to such heat treatment in heavy sections and provide safe strength characteristics in light sections.

4340 does the job on both counts

4340 chrome-nickel-moly steel provides 150,000/170,000 psi tensile strength in heavy sections. It also provides desired fatigue and shock resistance.

4340 solves the rotor hubs production problem, too. Even after machining away 75% of the metal, after heat treatment the remaining section has the desired high strength.

Vertol specifies 4340 steel for other rotor components

4340 also gives Vertol desired properties in vertical and horizontal link pins...rotor shafts...and planetary carriers. In other parts of the YH-16A, Vertol uses carburizing type nickel steels for strength and wear resistance, austenitic types to withstand heat and corrosion.

If you have a difficult design problem, chances are one of several grades of nickel alloy steels is the answer for you, too. Send us details of your problem and we'll be happy to help you make the right selection.

INCO TRADE MARK **THE INTERNATIONAL NICKEL COMPANY, INC.** 67 Wall Street New York 5, N.Y.

Specify FLUOROFLEX®-T assemblies because...

There's SAFETY in these numbers

Pat. No. 2,752,637 . . . for unique tube of Teflon

. . . **5 years** development and qualification testing

. . . **4 years** actual flight service

THERE *is* a difference in Teflon tubing—and there is a patent to prove it. Resistoflex know-how in Teflon-processing assures you high integrity lines . . . genuine *aircraft quality.*

Long before it was ever offered to the aeronautical industry, Fluoroflex®-T hose had withstood countless hours of standard and specially devised tests of the severest type without failure.

Now, approximately 4 years of successful experience *in flight* also back up your choice of Fluoroflex-T hose assemblies.

As the originator of Teflon hose, Resistoflex made a major contribution to flying safety. It has satisfied a vital need for leakproof, lightweight, corrosion resistant flexible lines to work at continuous operating temperatures of −100° F. to +500° F. Send for technical data.

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20th year of service to industry

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for a prove-it-yourself demonstration of the Honeywell VISICORDER®

We're sure, once you've seen the fabulous new Visicorder demonstrated, that you'll be as enthusiastic as the thousands of others who have watched the Visicorder in operation.

That's why we're inviting *you* to be the judge . . . to call your nearest Honeywell Industrial Sales Engineer.* He will set up a Visicorder demonstration in your office, plant, or laboratory . . . at your convenience.

The Visicorder, in the short months since its introduction has become the most wanted oscillograph in America. Why? Because the Visicorder records at frequencies from DC to 2000 CPS, with sensitivities that compare to photographic oscillographs. Because the stable, direct-reading Visicorder records are reproducible, and permanent under ordinary usage. Because the Visicorder bridges the gap between mechanical direct-writing oscillographs and photographic-type instruments.

So accept this invitation: Call your nearest Honeywell Industrial Sales Engineer today. He will arrange for you to operate the Visicorder yourself so that you can see for yourself how the Visicorder fits your most complex recording application.

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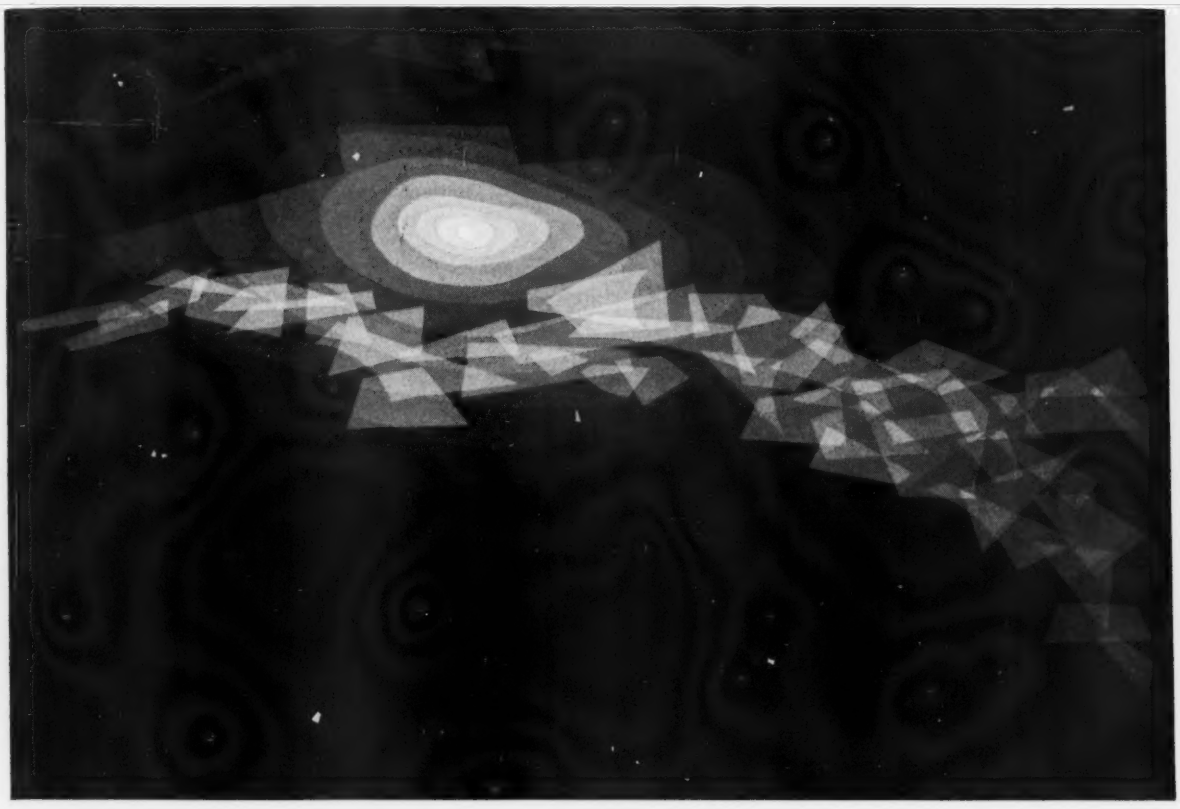
also ANNOUNCING . . .

The high-frequency Visicorder galvanometers have been redesigned to provide sensitivity improvements as great as 4 times, and a new 1000-cycle galvanometer has been added. All high-frequency galvanometers shipped after March 15 are to the new specifications.

•

*Visicorder demonstrators are now based in these Honeywell Industrial Sales Offices: Albuquerque • Atlanta • Baltimore • Boston • Buffalo • Cleveland • Dallas • Dayton Denver • Detroit • El Paso • Hammond, Ind. • Hartford • Long Island City • Los Angeles • Omaha • Pittsburgh • Philadelphia • Richmond • San Diego • San Francisco Seattle • St. Louis • Syracuse • Toronto, Ont. • Union, N. J. • Washington D. C. • Amsterdam, Netherlands • and more on the way.



"CYGNUS", another inspiration by Simpson-Middleman, painters of the meanings of science. "Knowledge of the Universe," say these artist-scientists, "is not a matter of man's sight, but of his imagination's vision. Our eyes show us Cygnus. But creations of our genius, such as the radio-telescope, reveal unexplored, unexplained sources of energy that man may someday master. They lie amidst and even beyond those mysterious, drifting clouds of cosmic matter, lit by the stars they do not obscure." Painting courtesy John Heller Gallery Inc.

You'll find an *interesting* future at Boeing

Boeing engineers and scientists are concerned with all phases of flight, including the problems of outer space. If you like to work in advanced areas of exploration, you'll be right at home at Boeing. Here engineers and scientists are busy on such projects of unusual interest as determining the performance of solar cells in flight environments encountered at altitudes up to 200,000 feet.

At Boeing, you'll work with men whose vision and extraordinary competence have helped open new eras of civil and military aviation. They invite you to join them. Boeing needs engineers of ALL categories, as well as physicists and mathematicians, for assignments in many fields-of-the-future, including advanced supersonic flight, electronic and inertial guidance, chemical fuel propulsion and guided missile weapons systems.

You can begin an *interesting* long-range career by dropping a note now to: *John C. Sanders, Engineering Personnel Administrator, Boeing Airplane Company, Department A-64, Seattle 24, Washington.*

BOEING

IMPORTANT DEVELOPMENTS AT JPL

The Jet Propulsion Laboratory is a stable research and development center located north of Pasadena in the foothills of the San Gabriel mountains. Covering an 80 acre area and employing 1600 people, it is close to attractive residential areas.

The Laboratory is staffed by the California Institute of Technology and develops its many projects in basic research under contract with the U.S. Government.

Opportunities open to qualified engineers of U.S. citizenship. Inquiries now invited.

The Corporal—A Complete Missile System

In the development of guided missile systems, JPL maintains a broad responsibility. From earliest ideas to production engineering—from research and development in structures, aerodynamics, propulsion and electronic guidance, through field problems and actual troop use—full technical responsibility rests with JPL engineers and scientists.

Not only is the "Lab" responsible for the missile itself, but also for any associated ground equipment needed to insure a complete tactical weapon system.

One product of this type of systems responsibility is the Corporal—a highly accurate surface-to-surface ballistic missile. This missile, developed at the laboratory and now in production elsewhere, can be found "on active service" wherever needed in the American defense pattern.

A prime attraction at Jet Propulsion Laboratory for scientists and engineers of unusual ability is the exceptional opportunity for original research afforded by close integration with such vital programs.

JOB OPPORTUNITIES IN THESE FIELDS NOW

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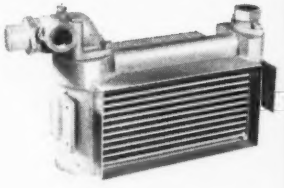
Harrison Cools Aero Design's Ultra-Modern Executive Transport!

New ideas in the sky . . . a new concept in airway travel! That's what this sleek, ultra-modern Aero Commander represents. It's fleet, maneuverable, comfortable . . . the ideal way to get there and *get there fast* for the modern business man. And it's Harrison that gets the cooling call on this popular new executive transport. Beating the heat for the most advanced aircraft is a Harrison specialty. It requires engineering skill, production know-how and the research facilities that you'll only find at Harrison. So remember . . . if you have a cooling problem, look to Harrison for the answer.

HARRISON RADIATOR DIVISION, GENERAL MOTORS CORP., LOCKPORT, N. Y.

GM GENERAL MOTORS

Watch "WIDE, WIDE WORLD" Sundays on NBC-TV



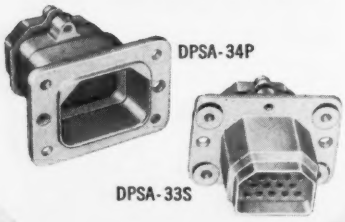
Lightweight, heavy-duty Harrison oil cooler is in command of heat on the advanced Aero Commander.

TEMPERATURES MADE TO ORDER

HARRISON

New!

DPS Connectors for High Altitudes-Vibration



DPSA-34P

DPSA-33S

These rack/panel pressurized connectors are designed for high altitude and vibration applications. When the DPS connector is mated, it is sealed about the insert faces by means of a specially designed rubber seal, that allows an axial tolerance of up to ⅛" while still effecting a seal. This seal is encased in the #34 shell so that the step down design of the mating #33 shell seats into and against it. In addition, the #34 or pin insert shell encloses a monobloc silicone insert designed so that the tightening of the junction shell effects a compression seal around the wires that have been inserted. The #33 or socket insert shell has a plastic front insulator, to insure alignment of contacts, and is backed up by a silicone rear insulator that is also tapered to permit the corresponding taper of the junction shell to compress it around the wires as the junction shell is tightened. Contacts for DPS connectors must be ordered separately, and installed at time of wiring. Co-axial contacts, and thermocouple contacts are available. Also, air lines. DPS connectors are available in 4 different sizes with several insert arrangements for each size.

Write for Bulletin DP-101 TODAY!

WHAT'S NEW FOR YOU

New!

Coaxial Connector Screw Type Coupling

TNC Coaxial Receptacle SA-445

Latest RF Connector Series—The TNC. The TNC is a screw type coupling version of the improved BNC series for small coaxial connectors. This TNC series, made by the Eastern Division of Cannon Electric, is available in two types: low voltage and high voltage. Both types are ideal where minimum noise is desired. They are lightweight, waterproof, sealed connectors which will operate at any altitude.

The high voltage TNC is recommended for AC rating up to 5,000 volts. Low voltage rating is to 500 volts. The TNC series is also available with collet cable clamp.

Write for RF Coaxial Bulletin DC-1 TODAY!

IN **CANNON PLUGS**

New!

Quick-Disconnect Accessories for AN-Plugs

CA06BQ Plug

CA02AQ Receptacle

An accessory that consists of coupler and an adapter has been recently perfected by Cannon to provide quick connect and quick disconnect characteristics to AN connectors.

The adapter is designed to screw over the coupling threads of a standard AN receptacle, and contains an external locking groove which receives the formed ends of the coupler latch when fully engaged. The entry of the coupler latch into this groove permits a compression spring to move the coupler sleeve forward, locking the parts securely. A simple straight pull back on the sleeve releases the latch and permits disconnection.

The coupler consists of a special spring latch assembly, and is designed to replace the coupling nuts on Cannon AN3106A and AN3106B plugs.

Write for Bulletin PR-QD TODAY!

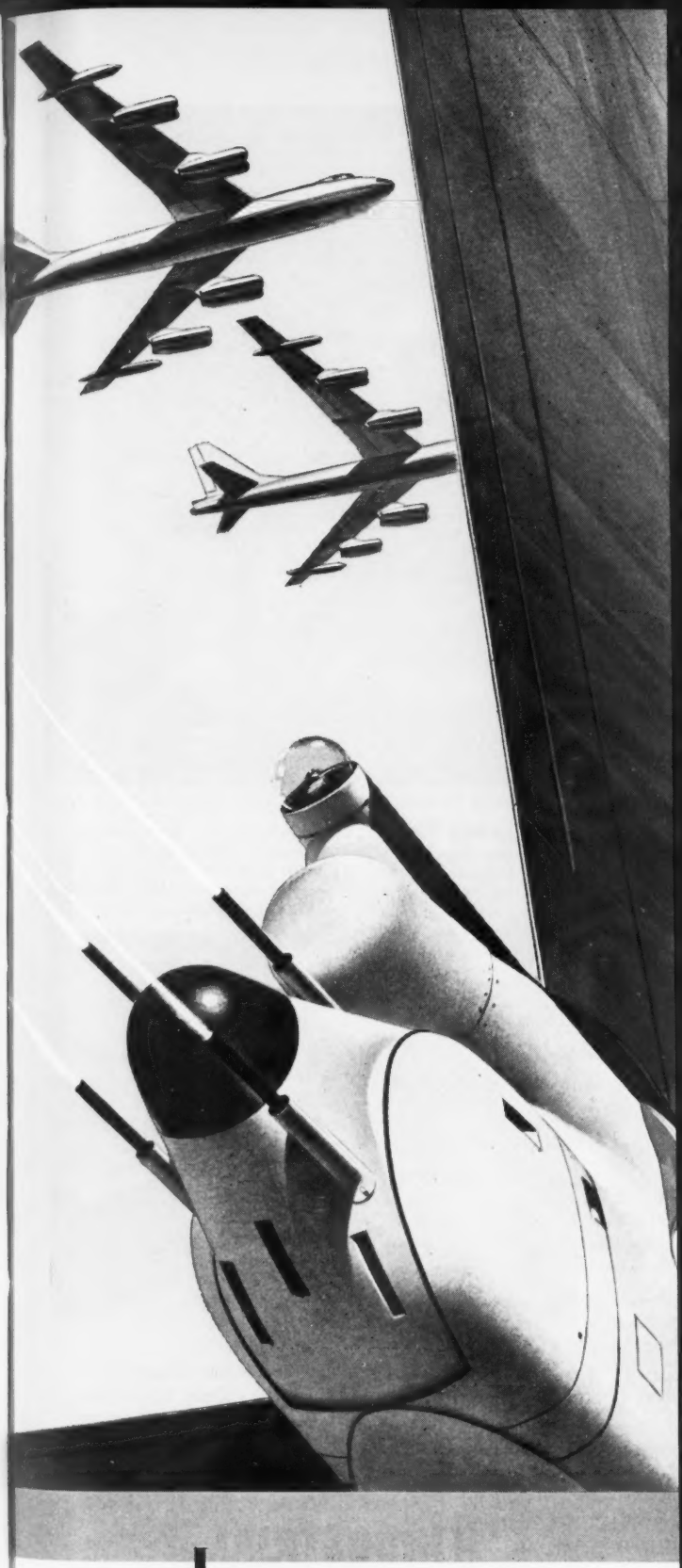
CANNON PLUGS

WHERE RELIABILITY IS THE 5TH DIMENSION

CANNON ELECTRIC

Please refer to Dept. 105

CANNON ELECTRIC CO., 3208 Humboldt St., Los Angeles 31, California. Factories in Los Angeles, Salem, Mass., Toronto, London, Melbourne. Manufacturing licensees in Paris, Tokyo. Representatives and distributors in all principal cities.



"TRIGGER FINGER" FOR SAC

Reliable protection is a *must* for Boeing's giant B-52, operational weapon of the Strategic Air Command. An Avco-Crosley-manufactured MD-9 fire control system—with dual radar and multi-weapon turret—provides deadly and almost completely automatic protection for the B-52.

This newest "stinger" is one of a long list of modern bomber defense systems produced by Crosley. And, looking to the future, Crosley scientists are constantly developing still finer protection for the aircraft of tomorrow.

Crosley offers complete facilities for research, development, and production of:

Air Weapons Systems
Ground Radar Systems
Air Traffic Control Systems
Ordnance Systems
Missile Systems
Aircraft Structures
Communications Systems
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ENGINEERS WANTED: For top-flight men, Crosley offers unusual opportunities to explore new scientific frontiers that lead to outstanding and rewarding careers. Write to Vice President of Engineering at Avco-Crosley.

SMALL ENGINE Test Cells—In this test house at Wen-Mac Corp., Los Angeles, California, technicians test engines for toy models. Noise inside is 100 decibels at high frequencies, but Koppers sound conditioning keeps outside level low enough for normal conversation.

LARGE ENGINE Test Cells—Large, permanent test hangars built by Koppers Industrial Sound Control Department provide sound-controlled testing facilities for the most modern and the most powerful engines throughout the aircraft industry.

KOPPERS *ISC* silences engines of any size

Big engines or little engines—it makes no difference . . . Koppers Industrial Sound Control Department silences the *noise* of any engine . . . whether it's from a run-up test of the newest super-sonic jet fighter plane . . . or from a severe testing of a number of small engines like the tiny (1/12 HP) but loud Wen-Mac engine for toy models.

Koppers ISC acoustical engineers custom-design sound-suppressing treatment for any industrial or aircraft noise problem. Test hangars . . . test houses . . . run-up mufflers . . . machinery enclosures . . . sound-proof rooms, shops and doors . . . air-borne mufflers—all are part of the normal sound control service offered by Koppers.

Solve your noise problems now—efficiently and economically. Boost worker morale . . . prevent litigation for hearing loss damages . . . maintain better community relations. For further information, write to KOPPERS COMPANY, INC., Industrial Sound Control Dept., 5906 Scott Street, Baltimore 3, Maryland.

KOPPERS **INDUSTRIAL SOUND CONTROL**

Engineered Products Sold with ***Service***

TAILORED TO WITHSTAND ENVIRONMENTAL HAZARDS

**Originally introduced as Bendix† Scinseal, this remarkable protective covering for wiring assemblies has achieved wide acceptance because of its versatility and adaptability to virtually any installation condition. Benseal is identical to the product produced under the former name Scinseal.*

If your operations require the use of wiring assemblies which must function in extreme temperature conditions or withstand other environmental hazards, you need the protection of Benseal. It is the perfect protective material for wiring assemblies and usually eliminates the need for metal conduits.

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IAS News Notes

June 1957

TWO IAS AWARDS to be presented soon are the Octave Chanute Award and Water-Based Aviation Award -- the first at the National Summer Meeting (June 17-20) "for a notable contribution made by a pilot to the aeronautical sciences." The Water-Based Aviation Award, presented to pioneers in the field at the last IAS Annual Meeting, may be made to an outstanding contemporary at the National Naval Aviation Meeting (August 5-10) "for meritorious work in the design or operation of water-based aircraft leading to advances in performance or utility."

* * * * * *

HONORARY CHAIRMAN for the Naval Aviation Meeting is Rear Admiral J. S. Russell, Chief, Bureau of Aeronautics. Field trips tentatively scheduled include a carrier visit, Miramar Naval Air Station air show, naval static displays at Miramar, and open house for the general public at all naval facilities.

* * * * * *

NEW CORPORATE MEMBERS of the Institute are Southwest Products Company, headquarters at 1705 South Mountain Avenue, Monrovia, Calif., and Kelsey-Hayes Company Aviation Divisions, at 3200 Military Avenue, Detroit 32, Mich.

* * * * * *

EDWARD P. WARNER (HF), Council President, International Civil Aviation Organization, is retiring after 11 years as leader of the ICAO. He will be succeeded by Walter Binaghi of Argentina.

* * * * * *

ROCKET AND MISSILE scientists who plan to attend the RAeS, British Interplanetary Society and College of Aeronautics symposium on high altitude and satellite rockets are reminded that applications for registration and accommodations must be received in Great Britain by June 29. They may be sent to: Warden, College of Aeronautics, Cranfield, Bletchley, Bucks, U.K. Accommodation is limited to 150 persons.

* * * * * *

DATELINE WORLD, the Review's new feature on scientific notes and reports from around the globe, appears initially in this issue on page 41.

* * * * * *

THE INSTITUTE SADLY REPORTS the death on March 26 of Modesto Panetti, an IAS Fellow prior to World War II and pioneer in Italian aeronautical science. Full details will appear in the necrology section of the July Review.

NATIONAL MEETINGS CALENDAR

6/17-20 National Summer Meeting, Biltmore Hotel, Los Angeles, Calif.

8/5-10 National Naval Aviation Meeting, U.S. Grant Hotel, San Diego, Calif.

9/1-15 Sixth Anglo-American Aeronautical Conference, Royal Aeronautical Society and IAS, London and Folkestone, Great Britain.

10/21-22 Canadian Aeronautical Institute-IAS Meeting, Montreal, Canada.

11/7-8 Weapons System Management Meeting, Statler-Hilton Hotel, Dallas, Texas.

12/17 Wright Brothers Lecture, Washington, D. C.

1/27-31 Twenty-Sixth Annual Meeting, Sheraton-Astor Hotel, New York.

* * * * * *

JOINT MEETINGS CALENDAR

6/19-21 1957 Heat Transfer and Fluid Mechanics Institute, California Institute of Technology, Pasadena, Calif. Cosponsored by IAS.

* * * * * *

SECTION MEETINGS CALENDAR

June 6 San Diego Section: Joint Specialist Meeting with ARS and ISA, IAS Building, 8 p.m. "Tracking of the Vanguard Missile" by Fred L. Whipple.

June 11 Los Angeles Section: Specialist Meeting, IAS Building, 8 p.m. "Optimum Burning Program as Related to Aerodynamic Heating for a Missile Traversing the Earth's Atmosphere" by Angelo Miele.

June 12 Texas Section: Specialist Meeting, Arlington State College Engineering Auditorium, 8 p.m. "Hydraulic Positional Servomechanism Analysis" by Gilbert E. Voyles.

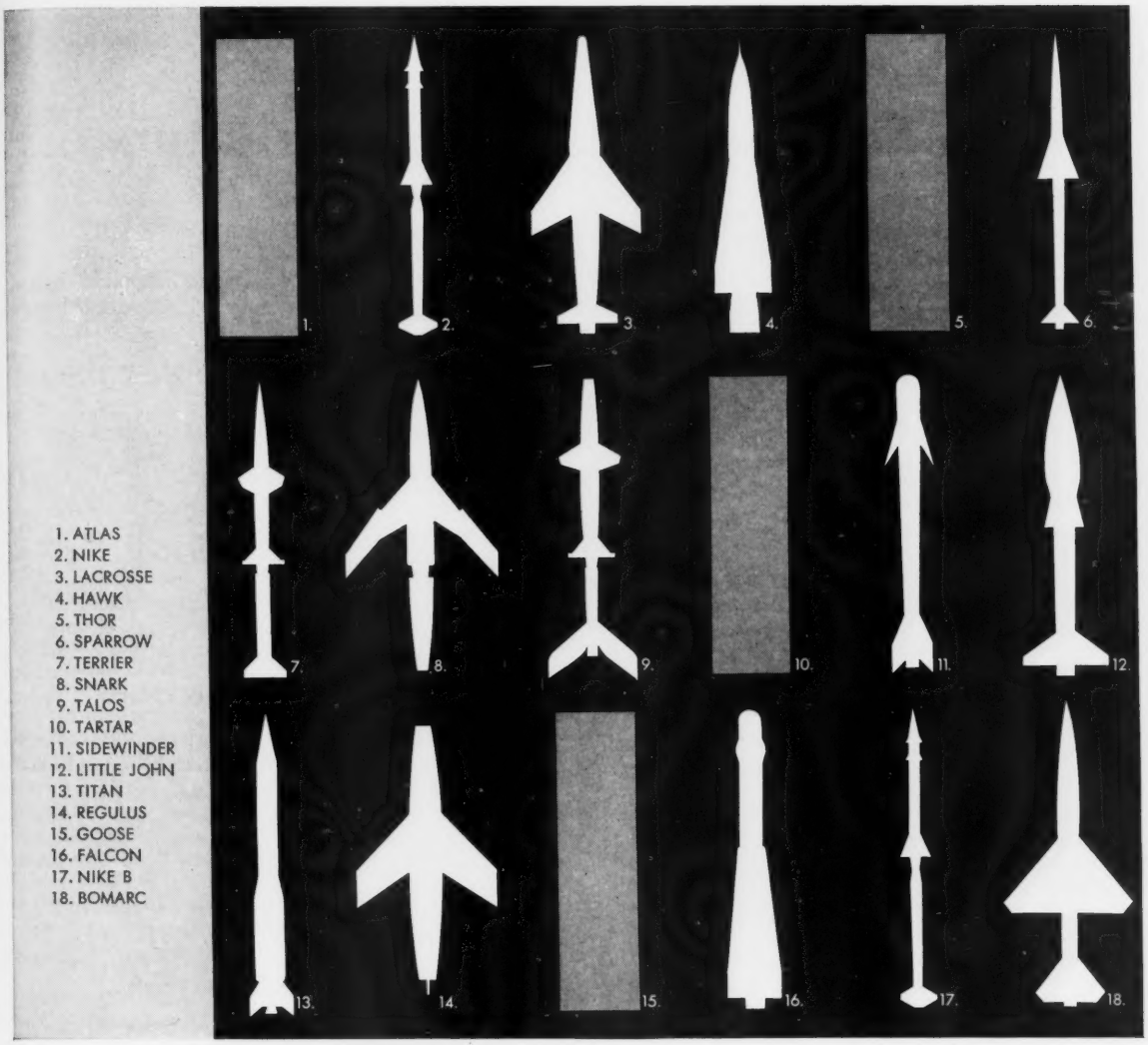
June 18 San Diego Section: Dinner Meeting, 6 p.m. Family Night.

June 20 Dayton Section: Dinner Meeting, Bldg. 100, General Electric plant, Evendale, Ohio, 6:30 p.m. "J-79 Engine" by Neil Burgess.

June 25 Los Angeles Section: Specialist Meeting, IAS Building, 8 p.m. "Rain Erosion Testing of Radome Materials" by F. R. Sedlund and J. Hurd.

June 28 Texas Section: Dinner Meeting, "The Martin Vanguard" (Speaker and place to be announced.)

* * * * * *



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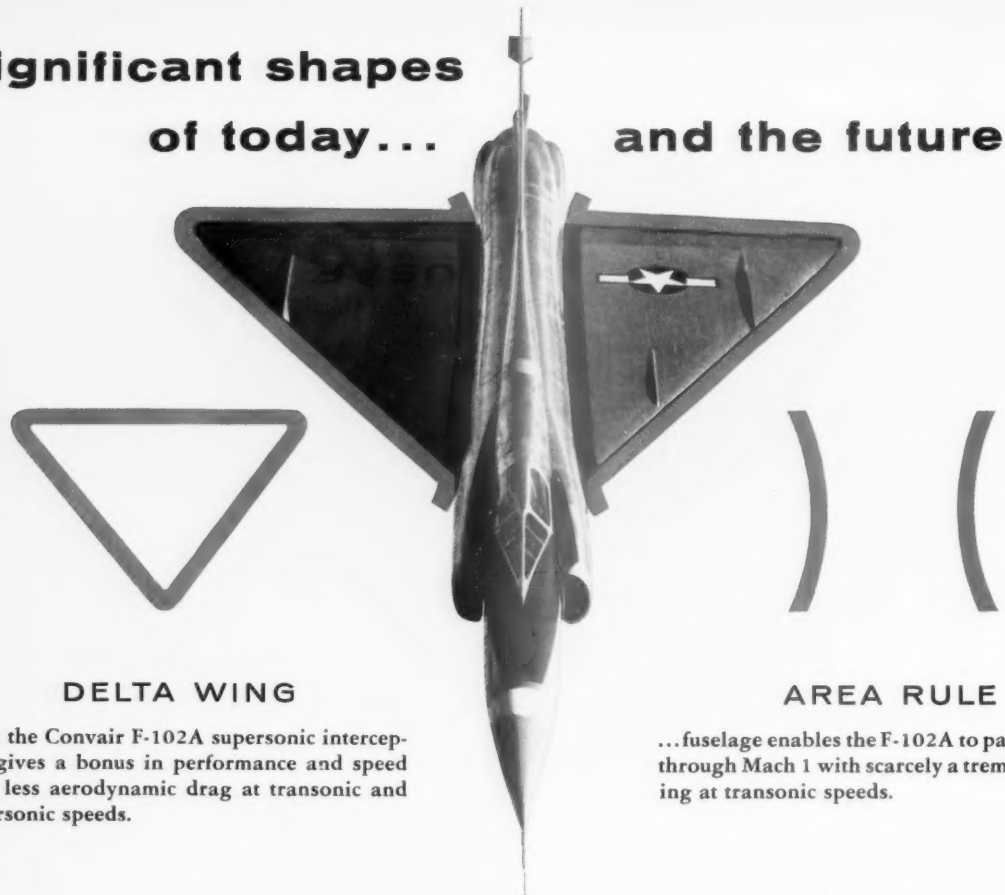

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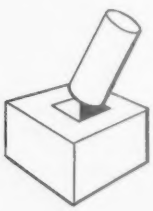

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IAS News

A Record of People and Events of Interest to Institute Members

12th Annual Flight Propulsion Meeting

Nuclear Energy, Missile Propulsion, and High Energy Fuels Highlight Classified Sessions and Dinner Speech

TWO DAYS of technical sessions, instead of the customary one-day meeting, drew a capacity audience to the Hotel Carter, Cleveland, in March. With eleven highly classified papers on the program plus three interesting discussions of nuclear power presented in open session, this year's meeting hit a new high in attendance and importance.

Much credit for its success and value goes to the U.S. Air Force, whose sponsorship and assistance made the whole thing possible. Technical support was supplied by ARDC, and the gigantic task of processing over 1,200 secret clearance applications was handled by the Cleveland Air Procurement District through assignment by the Mobile Air Materiel Area.

The classified papers presented at the meeting have been published by ASTIA and are available to established users of ASTIA services through that agency. It is expected that the three unclassified papers will be published by the IAS through the Sherman M. Fairchild Fund in the near future.

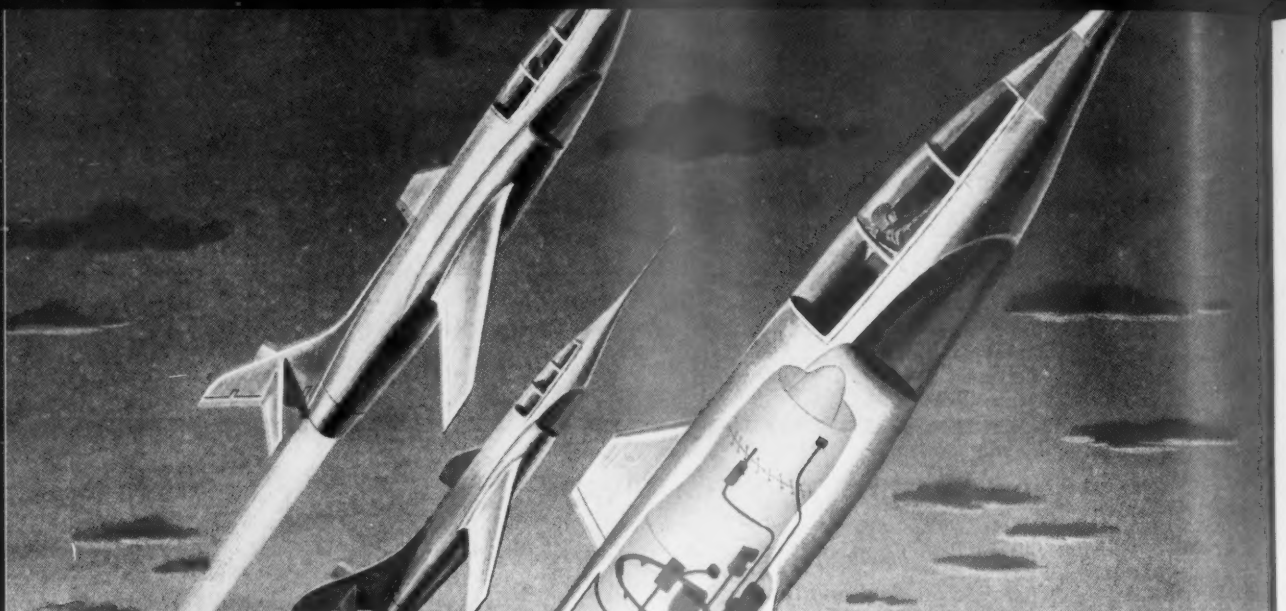
J. Carlton Ward, Jr., principal speaker at the Flight Propulsion dinner, traced the history of civilization's fuel and power sources and predicted the possible trends and developments in this field for the future. A condensed version of Mr. Ward's talk appears as a guest editorial in this issue under the title "Our Atomic Future" (p. 44). He was introduced at the dinner by IAS President Mundy I. Peale.

As usual, the local aircraft industries of the Cleveland area supported the meeting with some interesting exhibits. Companies participating in this year's program included: Aircraft Components Division of Ferrotherm, American Steel and Wire, Cleveland Pneumatic Tool, General Tire and Rubber, B. F. Goodrich, Goodyear Aircraft, Jack & Heintz, Pesco Products, Romec Division of Lear, Steel Improvement & Forge, and Thompson Products.

Newell Sanders, General Chairman

The classified nature of these annual Flight Propulsion meetings precludes any detailed reporting. However, it is no violation of security to state that this year's program, arranged and handled by officers and members of the IAS Cleveland-Akron Section and assisted by Past-President "Ray" Sharp's efficient NACA staff, was the best yet.

(*Left*) Allen Lowe, President of the Hotel Carter, presents key to the City of Cleveland to IAS President Mundy I. Peale, as IAS Director S. Paul Johnston and Past-President E. R. Sharp look on. (*Right*) Mundy Peale introduces the dinner speaker, J. Carlton Ward, Jr., seated.



TOWARD MACH 3

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When the pilot swings the lever from idle to emergency thrust—or back again—things must happen fast in the big jets.

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Bendix AVIATION CORPORATION

Navy Pilot Named Winner of Flight Test Fellowship

A 26-year-old Navy pilot has been named by the Institute to receive the 1957 Flight Test Engineering Fellowship.

Lieutenant (j.g.) Franklin F. Eckhart, Line Operations Officer in an Air Anti-Submarine Squadron at Quonset Point, R.I., was selected for 2 years' graduate study at Princeton University.

The award has a total value of $4,700 for tuition and stipend at Princeton, where courses in flight-test engineering have been taught to military pilots for several years. Lieutenant Eckhart, as a First-Year Fellow, receives $1,500 as stipend and $600 for tuition. Second-year renewal is contingent upon satisfactory performance during the initial year. A Second-Year Fellow receives $2,000 stipend and $600 for tuition.

Lieutenant Eckhart became a naval aviator in June, 1955, after completing flight training. He has logged about 900 hours in the SNJ, SNB, TBM, and S2F types of aircraft and also holds a CAA single- and multiengined land instrument commercial pilot's certificate.

He was awarded a Curtiss-Wright Scholarship while at the University of Michigan, where he received a B.S. degree in aeronautical engineering in 1953. Lieutenant Eckhart is a native of Palmerton, Pa., is married, and has two children. He will be promoted to the rank of full Lieutenant this month and will be released from active duty in September.

The Flight Test Engineering Fellowships are provided by an anonymous donor and administered by the Institute. One or more Fellowships are granted on a competitive basis by a Board of Award made up of Hugh L. Dryden, Director, NACA; Roger W. Kahn, Service Manager and Test Pilot, Grumman Aircraft Engineering Corporation; A. Scott Crossfield, North American Aviation, Inc.; A. M. Johnston, Chief of Flight Test, Boeing Airplane Company; and S. Paul Johnston, IAS Director.

Courses at Princeton are specifically designed to provide a solid foundation of advanced technical training in the science of flight test.

Lt. (j.g.) Franklin F. Eckhart (A), USN.

Rockets, Satellites Symposium Scheduled in Great Britain, July 18–20

A symposium devoted to problems of designing, constructing, and operating high-altitude rockets and satellite vehicles has been planned by the Royal Aeronautical Society, the British Interplanetary Society, and the College of Aeronautics at Cranfield, July 18–20.

Future nonmilitary applications and developments of rockets will be discussed in a program of lectures, prepared and informal discussions, films of rocket development, and an exhibition.

Accommodations will be available at the College for the full period, and a registration fee will be charged. Applications and further information are available through the Warden, College of Aeronautics, Cranfield, Great Britain.

Two IAS Corporate Members Sponsor Purdue Research Center

Two corporate members of the Institute, Lockheed Aircraft Corporation and the General Electric Company, are among 13 Founder Sponsors of Purdue University's new Thermophysical Properties Research Center. Y. S. Touloukian, Associate Professor of Mechanical Engineering, is Director.

Two long-range objectives have been planned for the center:

(1) To serve as a world center for research and for the collection, analysis, correlation, and dissemination of data on thermophysical properties.

(2) To provide unique facilities and opportunities for graduate study and research on thermophysical properties.

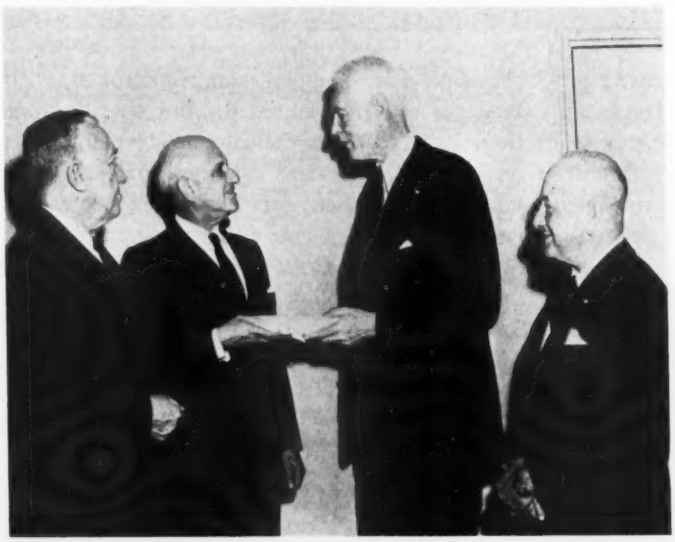
Section Seeks Material on Naval Aviation History

The San Diego Section of the Institute has broadcast an appeal to individual and corporate members for information on naval aviation history, particularly between 1910 and 1930.

The material is wanted in connection with the IAS Naval Aviation Meeting, August 5–10, in the U.S. Grant Hotel, where it will be added to historical material on display during the meeting.

No material is to be sent unless and until it is specifically requested. Information on any material may be sent to the Historical Committee, National Aviation Naval Meeting, Institute of the Aeronautical Sciences, 3380 North Harbor Drive, San Diego, Calif.

Harry F. Guggenheim (HF) *(second from left)*, accepts the certificate of the Laura Taber Award from J. Carlton Ward, Jr. (M), Chairman of the award board of the Flight Safety Foundation, Inc., while Dr. Clifford E. Barbour, Sr. *(left)*, award donor, and Rear Adm. Luis de Florez (F), USN (Ret.), look on. The award was created to recognize achievement in the promotion of flight safety—a branch of aviation in which Mr. Guggenheim has played a major role.



Nuclear Congress Papers Available

An *Availability List* for 1957 Nuclear Congress papers has been published by the American Society of Mechanical Engineers. Papers given at the Congress may be ordered from the list from the ASME Order Department, 29 West 39th Street, New York 18, N.Y.

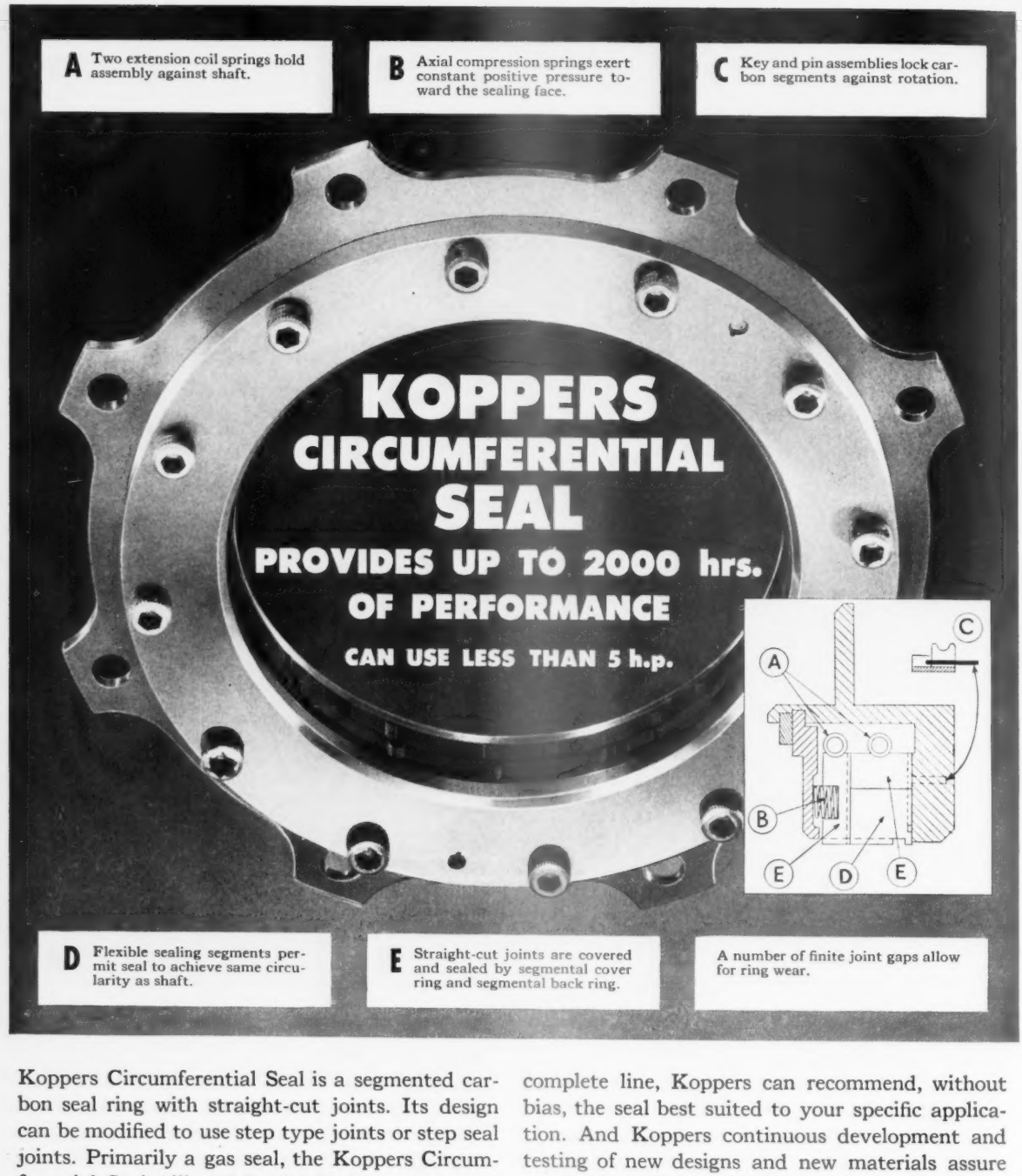
The list consists of 119 papers on various aspects of nuclear science. Papers may be ordered by list number only, $0.30 each copy. They will be available until January 15, 1958.

AGARD Wind-Tunnel Panel Plans Hypersonics Meeting

The Wind-Tunnel and Model Testing Panel of AGARD has scheduled a meeting on hypersonic aerodynamics and testing facilities, July 8–11, at Scheveningen, Holland.

The NATO research panel will cover theoretical work on hypersonic fluid mechanics, devices for hypersonic research (such as wind tunnels), gun-launched models, and rocket models. One day on the agenda has been set aside to discuss shock tubes and their uses.

(*Continued on page 82*)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DATELINE world

PROFESSIONAL NOTES AND REPORTS

Engineering and Scientific Briefs from Correspondents Around the Globe

New Soviet Stainless Steel Indicated; Has No Equivalent

◆ F. B. Slomyanskaya, in an article entitled "On the Methods of Testing Stainless Steel for Susceptibility of Intergranular Corrosion," indicates that the U.S.S.R. has a new stainless steel that has no known U.S. or West European equivalent. The composition undergoing tests has been designated by the Soviet system as Kh13N4G9 (Cr 13%, Ni 4%, Mn 9%). The 9% manganese, which is an austenizer, is a substitute for nickel which is unquestionably on the U.S.S.R.'s critical list. From the relatively low chromium content, it might be assumed that this grade is designed for high-temperature strength rather than corrosion resistance. The nickel and manganese contents are probably sufficient to give an austenitic material, which presumably would have fairly good elevated-temperature properties up to perhaps 1,500°F.

Japanese to Employ About 500 in Scientific, Technical Center

◆ Japan's Science and Technology Agency has completed plans for the establishment of a Scientific and Technical Information Center and thus has taken the first constructive step toward becoming operational since the agency was formed in March, 1956. The center will be operated on an annual budget of 200 million yen and will employ some 500 personnel. Construction of the center itself is expected to cost 600 million yen over the next 5 years (360 yen = $1.00).

Responsibilities of the center will include the collection of documentary data, catalog, official patent bulletins, and recent news on domestic and foreign science and technology. It will also maintain listings and states of activity of research organs, researchers, technicians, and enterprises. Initial emphasis is to be placed on scientific and engineering fields, while subsequent concentration will be on agricultural and medical branches. Japan plans to station technical attachés in the United States, United Kingdom, France, Germany, India, Switzerland, and southeastern Asian countries for the purpose of collecting foreign information.

The Technical Information Center is expected to be composed of five units: a Management Division, an Investigation Division, a Liaison Division, an Information Supply Division, and a Collection and Adjustment Division.

AGARD Model D Wing to Be Loaned by NACA

◆ Wind-tunnel operators may apply to NACA Headquarters in Washington to borrow AGARD Model D, which the French, through AGARD, have loaned to the U.S. The model is an elementary wing alone intended for testing, calibrating, and comparing different means and mechanisms for measuring dynamic stability derivatives by the forced oscillation method.

NACA tests of the model, which has a span of 78 cm. and a root chord of 20 cm., have been completed. Copies of AGARD Memorandum AG 4/M3 entitled "Specifications for AGARD Wind Tunnel Calibration Models," which describes the four AGARD models, may be obtained from NACA while the supply lasts.

Sneak Approach for Bomber Kill Is Advocated by 2 U.S.S.R. Pilots

◆ In "Herald of the Air Fleet," a Soviet pilot discusses in general terms fighter tactics to intercept a maneuvering bomber target. The article, although lacking realistic air speeds and altitude information, is interesting in that it deals with the concept of attacking contemporary bomber types equipped with a tail defense capable of detecting fighters by other than visual means.

Major L. I. Savichev discusses the subject in the March, 1956, issue and gives support to an earlier article on the same subject written by SAF Lt. Col. V. Makarov. It is the opinion of the two authors that the lower forward area of the bomber is not a likely area to attack because fighters can be detected by the bombing system. They suggest that the best approach is to sneak in toward the bomber at a relatively high or low altitude with respect to the target, thereby attempting to get within close range before being detected. To prevent detection is of primary importance since any evasive maneuvers by the bomber can increase the fighter's attack problem. The author stresses the point of adjusting air speed to that of the target when it gets within range, beginning the attack from above and to the rear and opening fire at either the same altitude or slightly lower than the target.

The article mentions a piece of equipment on the fighter called "sirena" which "would make it very difficult for the bomber to detect and locate the fighter." This description is suggestive of ECM equipment on the attacking fighter.

Japanese Parametron Computer Seen Sign of Electronic Skill

◆ A recent report indicates that the Japanese have completed building an electronic computer which uses 4,300 parametrons but no tubes or transistors. The parametron is a Japanese-developed device consisting of two ferrite discs, 4 mm. in diameter, and produced from a mixture of iron oxide, copper, and zinc. It reportedly was being used as an amplifier and was also being used in a new computer. Advantages of the new computer according to its manufacturer, Japan Electronic Measuring Instrument Co., Tokyo, are that it has fewer parts requiring replacement; is more economical, durable, and shock resistant; requires one third normal power; and has an almost unlimited life span. The computer adds and subtracts 1,800 times per sec. and multiplies 150 times per sec.

It is difficult to visualize an electronic computer without any tubes or transistors. However, there is no doubt that the use of ferrite devices (parametrons) would increase computer reliability and expedite miniaturization, both of which are still critical component problems.

The foregoing is another indication of steadily increasing Japanese electronic capability.

Metal Behavior Explained in Soviet Scientist's Paper

◆ In a paper entitled "On the Dislocation Theory of Metal Fatigue," I. A. Oding, eminent Soviet metallurgist, presents an equation relating the number of cycles for failure and the corre-

IF THE TRUTH MUST BE TOLD

. . . *by a spring*

This spring, the dependable heart of a leading make of air pressure gauge, must "tell the truth" years on end. But at first there were tough problems . . . and eventually the manufacturer turned to the Worcester Wire Works Division of National-Standard for a *special spring wire* that would solve them . . .

Look how the spring has a double pitch to properly take and indicate a wide range of pressure loads. Obviously, extreme accuracy, exceptional uniformity, and exact behavior are absolute musts. Rejects were running up to 50 per cent!

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DIVISIONS: NATIONAL-STANDARD, Niles, Mich.: *fine wire, stainless, music spring and plated wires* • WORCESTER WIRE WORKS, Worcester, Mass.: *music spring, stainless and plated wires, high and low carbon spec*

WAGNER LITHO MACHINERY, Secaucus, N. J.: *metal decorating equipment* • ATHENIA STEEL, Clifton, N. J.: *flat, high carbon spring steels* • REYNOLDS WIRE, Dixon, Ill.: *industrial wire cloth*

sponding stress based on present theories of dislocation and vacancies. In this paper, prepared in 1955, Oding considers that the nucleation of fatigue cracks occurs either by collection of vacancies (pile-up) or by their precipitation on the surface of favorably situated micropores. The collection of vacancies develops most effectively along the planes of maximum shear stress, while the precipitation of vacancies develops more effectively along the planes of maximum normal stress.

This dual theory, which leads to results quite different from the conventional Wohler representation, permits explanation of some of the peculiarities of the behavior of metals under asymmetric torsion cycles. The final equation is similar to that developed empirically by Weibull on the basis of a statistical analysis of Ravilly's data.

In accordance with the equation, the fatigue curves become straight lines when plotted in logarithmic coordinates [log (stress causing failure − endurance limit) vs. log cycles to failure], but, as illustrated by Ravilly's data, there is a change in slope which is believed related to the above indicated dual mechanism. This is interpreted as meaning that, at high stresses, failure occurs as the result of pile-up of vacancies and, at low stresses, failures result from precipitation of vacancies. Although the same equation applies in both cases, the coefficients must be changed since the two reactions proceed at different rates.

It is interesting to note that, on the subject of metal fatigue, Oding has for several years leaned heavily on the dislocation theory which originated in the West.

Note on the Theory of Fracture Under Combined Stresses

M. Zaustin*
California Institute of Technology

In his recent article, Topping** remarks, "The 'tangential' and 'normal' stresses he (Zaustin) speaks of appear to be based on a two-dimensional conception of the brittleness-stress relation."

The stresses of which this author† speaks are breaking stresses and, therefore, obviously maximum shear and maximum normal stress. The maximum shear stress is the greatest of the three principal stresses

$$\tau_{max} = (\sigma_1 - \sigma_2)/2 \quad \text{or} \quad (\sigma_3 - \sigma_2)/2 \quad \text{or} \quad (\sigma_1 - \sigma_3)/2$$

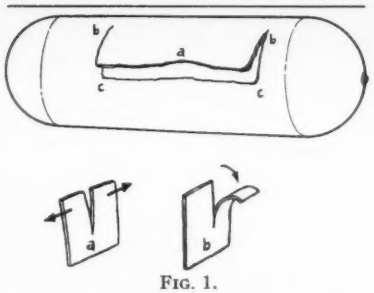


FIG. 1.

but, in cases of pressure vessels, the radial stress is much smaller than the other two and may be neglected (say, $\sigma_2 = 0$). This is especially permissible because the radial stress is compressive and therefore contributes to ductility and safety. Neglecting this stress is not quite the same as having a two-dimensional conception of the "brittleness-stress relation." Two-dimensional stresses do not exist in nature and should not be confused with two-dimensional loading. The state of stresses in this case is still triaxial, and the maximum shear stress still will be the greatest of the three,

$$\tau_{max} = (\sigma_1 - 0)/2 \quad \text{or} \quad (\sigma_3 - 0)/2 \quad \text{or} \quad (\sigma_1 - \sigma_3)/2$$

The situation is entirely different in a case of a notched bar in tension. Here no stresses can be neglected, and this test is used for determination of the basic physical property of metals—cohesive strength. It is not a reference test in the sense used in theories of strength; nor has it anything to do with the gradual transition from ductile to brittle state. The mechanism of this transition is controlled by the shear strength of metals which increases with lowering temperature or increasing strain rate and finally becomes greater than the cohesive strength. Then the result is a brittle fracture.

As to the normal stress, the "reduced" normal stress is used, which is given by

$$\sigma_{max} = \sigma_1 - \eta\,(\sigma_2 + \sigma_3)$$

Ductility is not a "function of octahedral normal stress." It is a function of two ratios—the ratio of shear stress to normal stress, on the one hand, and the ratio of the shear resistance of the material to its cohesive resistance, on the other hand. Thus, it is a result of the properties of the material as well as of the stresses.

Being a function of four parameters, it can be expressed mathematically with the same degree of accuracy as stresses can be calculated and strength measured. All depends on which of the two strengths of a metal will yield first to the corresponding stress. In this author's example,† the ratio was taken equal to 0.23 because the tank was sub-

* Research Engineer.

** Topping, A. D., *Behavior of Materials Under Combined Stresses in Pressurized Structures*, Aeronautical Engineering Review, Vol. 16, No. 2, pp. 56–59, February, 1957.

† Zaustin, M., *On the Danger of Combined Stresses in Pressurized Structures*, Aeronautical Engineering Review, Vol. 14, No. 12, pp. 45–48, December, 1955.

† Zaustin, M., *op. cit.*

(Continued on page 115)

New Work Is Held Valuable in Testing Air-Weapons Metals

◆ A Soviet paper entitled "Hardness and Stress in Plastically Deformed Bodies" reveals excellent investigational work which should be valuable in testing air-weapons metals. For purposes of the investigation, the authors, A. M. Rozenberg and A. A. Khvorostukhin, assumed that indentation hardness is a measure of resistance to plastic deformation—an assumption which is not new, although the validity of this relationship has at times been questioned.

The paper, prepared in 1955, surmises that, since stress in the plastic region is related to the degree of deformation, the hardness number should be a function of the degree of deformation in the area of the indentation. Thus, by measuring the hardness of a previously deformed body, it should be possible to determine the stress of the previous plastic deformation. The functional relation between normal and tangential stress and hardness should be valid for all metals and all types of deformation.

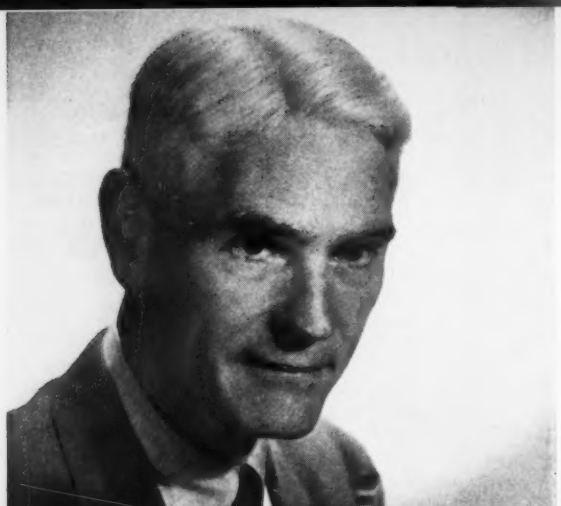
In checking the validity of this theory, tests were conducted using carbon steels 10 and 4; alloy steels ShKh15, 30KhGS, 9KhS, 12KhN3A, and EYa1T; and aluminum, red copper, and cast iron at four hardnesses. Plastic deformation was produced by compression, tension, torsion, and cutting. Hardness was determined with a diamond-pyramid indentor under a load of 5 or 10 kg. The tests revealed:

(1) For deformation by compression, tension, or torsion, the tangential stress was equal to 0.19 times the hardness number for a wide range of hardnesses from 42 (for aluminum) to 365 (for EYa1T).

(2) The same relation applied in cutting tests over a wide range of cutting conditions. The hardness was measured in the zone of "primary deformation" of the chips—i.e., where the chips had been deformed by shear but not by actual contact with the top surface of the tool. This relation can be used to calculate the cutting force necessary to remove chips.

(3) Although the heat developed in the various types of plastic deformation varied considerably, this evidently did not affect the validity of the equation developed.

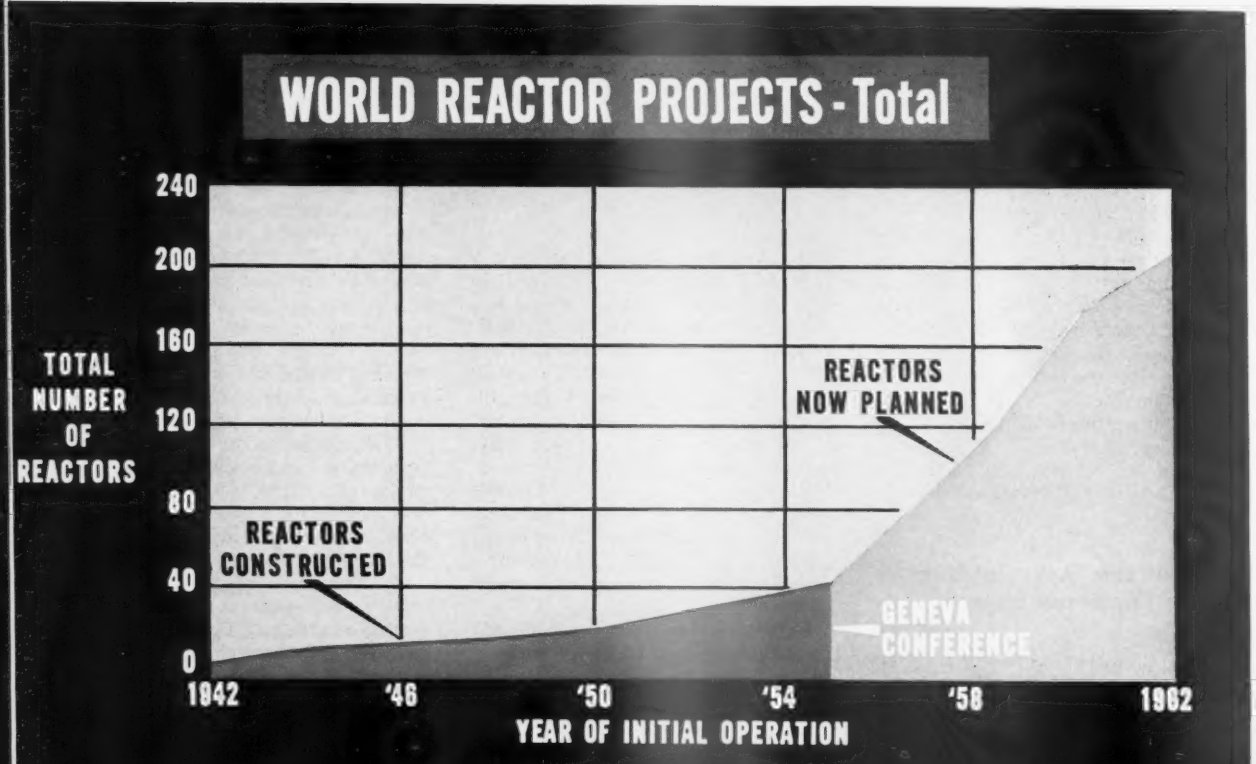
The fact that the stress involved in previous plastic deformation can be calculated from the hardness of the plastically deformed metal is clearly of considerable value in investigating samples with unknown history. Its applicability to machining should simplify experimental techniques by making possible an approximate calculation of cutting force from hardness tests on chips.



GUEST EDITORIAL

by J. Carlton Ward, Jr.

A condensation of a dinner address by the President of Vitro Corporation of America made at the 12th Annual Flight Propulsion Meeting of the IAS, Hotel Carter, Cleveland, March 14, 1957.



The revelations of the Geneva Conference caused a great upsurge in Atomic Reactor Development. This curve shows the projection for the next 5 years.

WORLD'S LARGEST—The Joint Nuclear Research Institute's proton-synchrocyclotron near Moscow, the successful operation of which has just been announced: This machine is several times larger than any in the United States. It was designed to reach 10^{10} electron volts. A machine five times this size is reported under development.

Sovfoto

OUR *Atomic* FUTURE

Cosmologists and anthropologists tell us that man has been known to be on this planet for a little over a million years. I believe some remains of a campfire were found in East Anglia in England about 10 years ago. By means of the atomic clock (that is, by studying the carbon left in some bones and the campfire), it was determined to be over a million years old. This explodes some of the current theories about where we came from and indicates that we've been on this planet as a species for quite a period of time.

During the first million years, our available energy came largely through the process of eating protein materials and then using the muscular energy that it developed. Civilization really didn't get very far until we began to discover some of the properties of the world around us, as to both energy and material. Very few natural forces (except from the winds) were utilized until about 1700 when a very simple steam engine was built for pumping water out of deep mine shafts in Wales. This started the Industrial Revolution, the harnessing of natural power for the driving of machinery for the production of goods.

Now this country was somewhat late in adapting these newer forms of prime movers. We had a lot of water power in and around New England, and this early became our chief source of energy. More and more mechanization followed and led finally to mass production and what today we call "automation."

There would be no aircraft industry without energy sources and power machines and generators. It is possible to glide or to balloon for considerable distances, but it is very difficult to accomplish very much that is useful this way. We could not have developed our industry as a part of modern civilization without some knowledge of energy sources. We are large users of energy. There is a simple rule that the energy required to move anything cubes with the speed. It doesn't matter whether you are pushing a wheelbarrow or riding a bicycle or flying an airplane: If you double the speed, you have cubed the amount of fuel or energy needed per unit of time. This rule is one that we must consider very seriously.

In no industry is the demand for energy as insatiable as in ours. This has led to a search for new and more prolific sources of energy. There are substances in nature which in a chemical reaction will give up to 50 per cent more energy per pound of weight than will our traditional petroleum fuels. It would be wonderful if we could go on this way and get 50 per cent more, then 50 per cent, and so ad infinitum. But, unfortunately, this won't work. If this *could* be done you would save the taxpayer enormous sums of money!

Now let us turn to a new source of energy—atomic energy. Very interesting work is going on in this area, and much is now known about tapping this force from nature. The things that engineers and scientists do generally are evolutionary, but the discovery of how to release atomic energy was revolutionary. It was not realized until Dr. Einstein produced his famous theory in 1905 that energy and matter are the same thing. When energy is released nothing has been destroyed, and, under suitable conditions, energy may turn back into matter.

Civilization is simply a product of energy put to use. The living standard index is the sum total of all goods produced plus all the services that are produced, divided by population. But we can't produce anything today without energy; therefore, the energy available in any

given country divided by its population is a measure of its standard of living, of its economic strength, and of its economic potential for national defense.

In the past 50 years (through the periods of two wars), it turns out that the curves of total electrical energy available per unit of population and the living standard indexes calculated by the Department of Commerce for the United States follow each other very closely. This says to us as engineers that the amount of energy which we have available will determine our standard of living and our national security.

Consider what the public utility industry of this country is planning in the way of expansion in electrical energy to run the United States in the period ahead. The curious rule is that about every 10 years the amount of electrical energy consumed in the American economy doubles. This is a fantastic rate, but the same thing is also going on in Western Europe and in other countries. They are proceeding along the same exponential curve as we are.

Recently, the British announced a program of building 15 million kilowatts capacity from atomic energy in the next 5 to 8 years. This has worried many people in the United States. The point is that the British do not have the sources of raw material in fuel that we have in the United States. They cannot produce the coal that they need to run their economy, and they do not have the dollars to pay for the coal from the United States. Overseas they are going into atomic energy in the quickest, easiest way because they have to. We, on the other hand, are trying the engineering-scientific approach toward tapping atomic energy by a wide variety of kinds of atomic plants. We do not propose to build a lot of monuments to inefficiency. We plan merely to produce power at a higher cost by atomic fuels.

All of the things talked about here are the products of research. The first industrial research laboratory in the United States was not organized until 1903. The total amount of research done in the United States was almost nil until World War I when we found ourselves shut off from the chemicals of Germany. In World War II research came into its proper place. There was an enormous upsurge to 1 billion dollars a year from what had been around a quarter of a billion dollars. But at the war's end the pace of our research was in serious danger of being abandoned.

We of the aircraft industry had a great deal to do with holding the fort. In fact, it was in testimony before a Senate committee that the chairman asked me the question, "Why should we continue research?" I was testifying then as a member of the industry, on behalf of the industry. I said to the Senator, "We've got our bombs but we can't deliver them, because there is no such thing as a bomber that can escape from a modern interceptor. If we fly low enough to be sure of our quarry, we'll encounter antiaircraft fire in the form of missiles and radar-sighted artillery." He was alarmed—duly alarmed—and asked what we should do. I said, "You can't build any kind of chemically fueled bombers that will outrun, outmaneuver, and outfly a chemically fueled interceptor." And I gave him the power cube rule. I said further, "There is only one source of energy left that you can use where this rule would not apply, since, because of its weight, an atomic power plant cannot be put in a pursuit airplane. But it can be put in a bomber. . . and with an atomic power plant you could keep going around the world as long as the coffee and sandwiches hold out for the crew." On that day atomic propulsion for airplanes was born. But an expanded research program was the essential requirement.

Until World War II, the amount of research done in the U.S. Government, including NACA, the Department of Agriculture, the Bureau of Standards, and all the great laboratories, was very small compared to the amount of research done in industry.

With the threat of war the research supported by the U.S. Government became far larger than the research supported by private industry and remained so until the slack began after the war. In spite of our industry's testimony in Congress, research was not maintained at the war pace, but it was not, however, cut back as had been planned by economy-minded congressmen at that time. During the Korean War the Government again took the lead in money furnished for research. Our total research is now at about 5 billion dollars a year, and people in the know are predicting it will be from 6 to 8 billion a year in the next 3 years.

Vannevar Bush said in his famous book that we used up 50 years of fundamental research in the 5 years of World War II and that this was one of the most serious things that could happen if we didn't do something about it. We have done something about it. The universities, for instance, have taken a role in American affairs which they never have had traditionally. Of the dollars spent in the United States for research before the war, 3 per cent was spent in universities. Today it is nearer 10 per cent. This is where the bulk of the basic research is done. Applied research would be meaningless if it did not have new basic research on which to feed.

The United States which formerly depended upon Europe's basic research has finally become sophisticated. Our basic research is beginning to increase in step with our applied research and development. This is one of the healthiest things that could have happened to the American economy.

The biggest research effort that you are making as a taxpayer is in atomic energy. You have now, as a taxpayer, invested up to 7 billion dollars in the atomic facilities owned and operated by the United States. Your annual operating cost is over 2 billion dollars. A large share of this goes into research. It is in this area that metallurgy is being remade; it is in this area that the atomic energy of the future is being planned.

The next portion of Mr. Ward's speech was a fascinating review of the sources of energy left in the world. He pointed out that we have already used most of the easy-to-get energy since the beginning of the Industrial Revolution

and that the economical known sources of chemical fuels will begin to be exhausted in less than 100 years. He predicted that the use of oil as a fuel may shortly be economically outlawed to prevent the exhaustion of our chief source of basic industrial organic chemicals. He then explored other known energy sources including solar energy and terrestrial heat and also took a look at the availability of the basic uranium and thorium ores in the United States. His conclusion was that our only hope lies in the development of nuclear and atomic energy, and he forecast (see chart) a very great expansion in world reactor projects over the next 5 years.

As we know, the Nautilus went over 60,000 miles or $2^3/_4$ times around the earth and actually used a calculated $8^1/_3$ lbs. of uranium. Think of $8^1/_3$ lbs. of fuel sending a submarine $2^3/_4$ times around the earth. This would ordinarily take some 57,140 barrels of oil! Obviously, this has made naval history.

Our officially proposed new atomic navy is a fantastic thing. Fifteen submarines are already on the way, two built, and the balance authorized. Atomic propelled cruisers, atomic power plants for carriers, atomic oilers, atomic merchant ships are all in development stages. This, coupled with the fact that the Navy can launch vehicles with atomic warheads, means that we have mobile bases from which we can reach any part of the world without yielding to the sovereignty of any other nation. This is a very fortunate fact. This is a checkmate to any form of political pressure to undo the peripheral land defenses which we have built for our protection against any enemy air force.

Take a good look at the picture (pp. 44, 45) of the Russian 10-billion electron volt proton-synchrocyclotron at the Central Institute of Nuclear Research near Moscow. This instrument has 36,000 tons of magnetic steel and is 200 ft. in diameter. The largest American instrument of that sort is 6,000 tons. I would like to have this stay in your mind as a symbol of the fact that this race is for keeps and *not* against a semibarbaric people aided by a few imported German scientists. Our own scientists have seen this facility. They tell me that there is no new principle in this machine unknown to us but that the engineering of the machine and its myriad auxiliary systems is generally superior to the engineering of similar American equipment.

So, we are not in this race alone. We are not keepers of the Creator's secrets in this field. We are in a deadly serious race. The weaponry that emerges from this new atomic force extends to every type of land, sea, and air warfare. We must continuously extend and intensify our research effort in these fields if we are to continue to be able to defend ourselves against all comers and to improve and assure our peacetime economy.

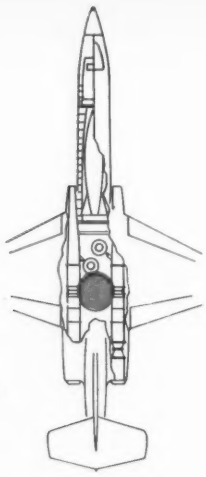
▲ ▲ ▲

IAS Twenty-Sixth Annual Meeting

Hotel Sheraton-Astor, New York City, January 27–30, 1958

The Meetings Committee plans to schedule sessions on Aerodynamics, Aeroelasticity, Design, Electronics, Flight Propulsion, Instruments, Rotating Wing Aircraft, Safety in Flight, Structures, Air Transportation, etc.

Members or organizations wishing to have papers considered for presentation at this meeting should submit outlines or short abstracts to the Meetings Committee, 2 East 64th St., New York 21, N.Y., no later than August 1, 1957.



Design of Air Frames for Nuclear Power†

Clarence L. Johnson* and F. A. Cleveland**
Lockheed Aircraft Corporation

One of the greatest latter 20th century challenges facing aeronautical engineers in several fields is development of an air vehicle which can avail itself of the tremendous advantages of nuclear energy. This paper, recently declassified and presented exclusively in the REVIEW, *airs publically for the first time many air-frame problems which must be surmounted before the atom can be packaged aloft, used efficiently and safely, and the Nuclear Air Age is born.*

INTRODUCTION

WITH THE increasing activity in the field of nuclear power for aircraft, it seems in order to discuss some of the technical features and problems connected with aircraft so powered. Naturally, security limits will prevent extremely detailed presentations on many aspects of design features of nuclear-powered aircraft although every year makes the feasibility of the type more and more a certainty. Many problems which seemed insurmountable a few years ago have proved to be of a rather minor nature or nonexistent; others, unexpected, have appeared.

The use of nuclear power is of great interest to the aircraft designer because it provides a means for giving the airplane nearly infinite range, to all intents and purposes. After a half century of striving to make aircraft carry reasonable loads farther and farther, the advent of a type of power plant that will solve the range problem is of the utmost importance. To be able to base military aircraft in the United States and still have a striking power any place in the world is a goal worth striving for. The tremendous implications in the elimination of foreign bases, with the great savings in cost to the taxpayer, are a great factor in encouraging work on the nuclear aircraft. We are reaching the limit of range with our conventional power plants and are having to resort to air-to-air refueling procedures to obtain reasonably acceptable radii of operation.

The majority of the papers which have been written to date on the application of nuclear power to aircraft have dealt almost exclusively with the power plant itself, only cursorily with the air frame. Those of Kalitinsky, Leverett, and Silverstein were focused on the inherent problems involved in perfecting an airborne reactor-engine propulsion unit; the first two of these were somewhat concerned with the feasibility of creating such a power plant *at all* in a practical form. Hibbard's address to the Air Force Association in the spring of 1954 dealt more with integrated air-frame - power-plant aspects of nuclear-powered airplanes but, of necessity, fairly briefly.

It is the intent of this paper to explore the nuclear-powered airplane almost exclusively from the viewpoint of the air-frame designer. It is hoped that such an examination will bring to light the real impact of the new propulsion concept by revealing the differences occasioned in the air-frame design and by casting them in terms of advantages, or disadvantages, in the design of a useful air frame. It appears that the strategic bomber, by requiring both high speed and great endurance and because of the inherent low-altitude potential advantages over similar chemical airplanes, will be the first candidate for a nuclear power plant.

We will eliminate chemical augmentation as a significant feature of the airplane operation mainly to keep the discussion more straightforward. We are thus discussing only the all-nuclear airplane with the

† Presented at the IAS Los Angeles Section Dinner Meeting, May 23, 1957.

* Vice-President—Research and Development.
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exception that some chemical fuel is carried for take-off and landing go-arounds.

As currently proposed (Fig. 1), most of the nuclear power plants are large and clumsy, even without considering the shielding required for personnel safety. The nuclear power plant in its early form is inefficient primarily because of the low temperature limits of the operating cycles. These limits are set by the ability of current materials to stand high temperatures. When improved materials are available, we would expect the nuclear power plant to advance rapidly in its overall efficiency, with a consequent improvement in ability to install such power plants in airplanes of smaller size than those currently contemplated.

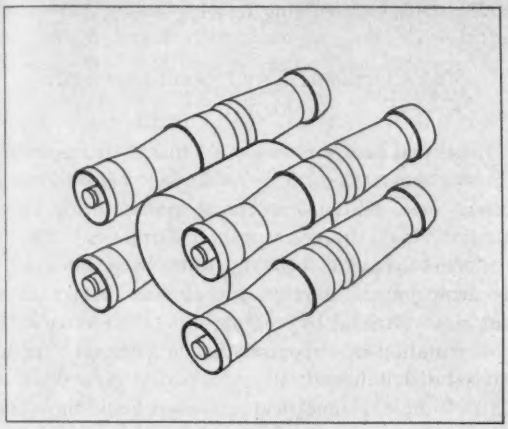

FIG. 1. Typical power plant.

BASIC POWER-PLANT CHARACTERISTICS ARE THREEFOLD

In order to clarify and categorize the air-frame reactions to the presence of the nuclear power package, let us first determine just what the basic characteristics of the power plant are which dictate their recognition in the air-frame design. In their most elementary form, they are only three:

(1) A highly concentrated weight in the reactor.

(2) A powerful radiation field emanating from the reactor.

(3) No consequential flight endurance limitations by the power-plant fuel.

We believe that the first of these characteristics is quite familiar. The reactor with the shielding attached to it, generally called the "reactor-shield assembly," is a very dense affair. It may weigh from 25,000 to 100,000 lbs., but, instead of having a density of 20 to 25 lbs per cu.ft. (as have modern turbojets) or 50 lbs. per cu.ft. (as has typical chemical fuel), the reactor-shield assembly may have a density of from 100 to 200 lbs. per cu.ft. We will explore the implications of this concentration of mass later.

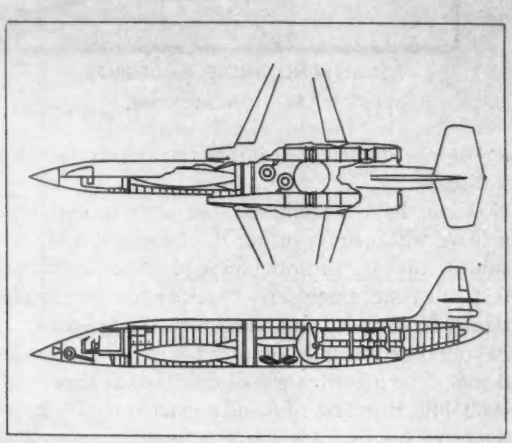

FIG. 3. Typical inboard profile.

The radiation field from the reactor proper is also well known. If it were possible to put as much shielding on the reactor as is done on ground reactors, we could reduce the radiation therefrom to a negligible amount. But the total weight of shielding required to do this would be prohibitive; in fact, we are forced to the so-called "divided shield" concept in order to reduce the total shield weight to an acceptable amount. Divided shielding (Fig. 2) is, of course, simply a division of the shielding between the reactor and the crew compartment in such a fashion as to result in near-minimum total shielding weight. As is apparent from the illustration it is possible to go too far in either direction and, as we will discuss later, the optimum dividedness is not a function of total shield weight alone but must also be compromised in recognition of several other factors. Divided shielding, then, while permitting lower radiation levels in the crew compartment for a given total shield weight, actually results in *higher* radiation levels every place else in and around the air frame.

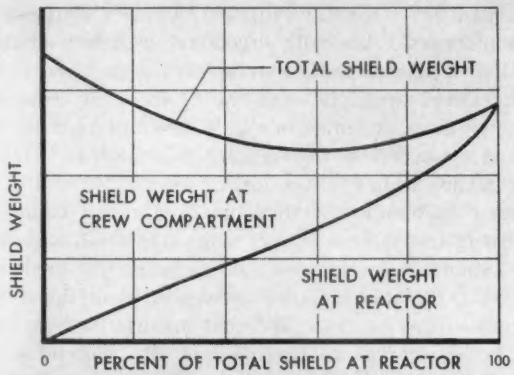

FIG. 2. Shield dividedness effect on total shield weight.

The third power-plant characteristic is the most familiar and is the fundamental reason that we are in this business at all. Its significance in a major sense is quite obvious; in many minor senses, however, it

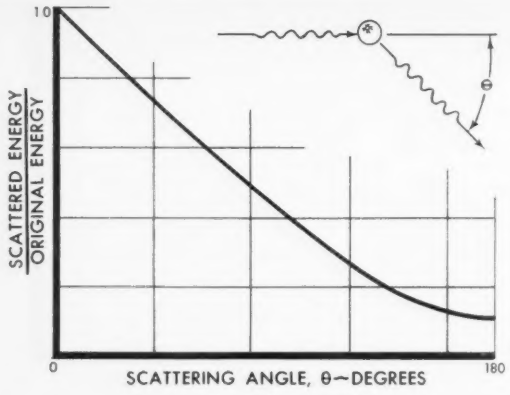

FIG. 4. Radiation scattering.

leads to less familiar, but interesting, effects which we will discuss.

Now we have established the assumptions under which we will operate in our discussion, and we have classified the important power-plant characteristics which will bear, singly and together, on our airplane design. We propose first to examine the disadvantages of having the nuclear propulsion system in the airplane, and second, to investigate the benefits to be expected.

Probably the first difficulty encountered by the designer in his first layout of a nuclear-powered air plane is the tremendous congestion at the center of gravity of the airplane (Fig. 3). It appears to be generally desirable to have the engines in close proximity to the reactor to reduce the many problems of transferring the reactor heat output to the engine air. The combination of the reactor shield assembly and the turbojets accounts for something in excess of 50 per cent of the airplane equipped weight empty. The wing, if unswept, certainly passes through the fuselage in the c.g. area. The center of gravity of the fuselage structure inherently lies close to the airplane c.g. The main landing gear must lie very close to the airplane c.g. Aircraft fixed equipment tends to be spread out in the fuselage and cannot be very helpful in rebalancing. About all that is left to aid the designer in pulling the c.g. away from the power plant are the crew compartment shielding and the empennage.

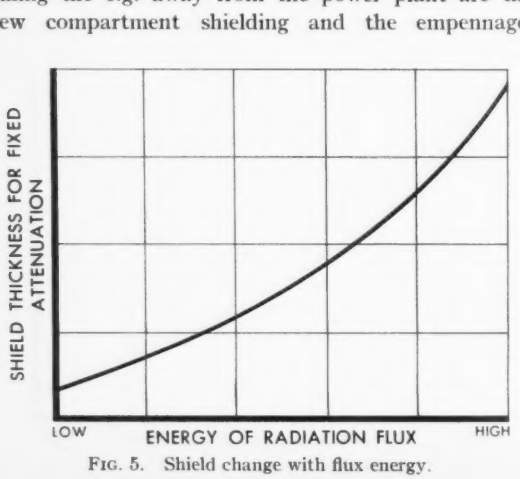

FIG. 5. Shield change with flux energy.

The latter of course operates so as to cancel part of the effectiveness of the crew shield in this respect. It is apparent, then, that the power plant, the main landing gear, the wing, and—to reduce c.g. travel—the disposable load all vie for fuselage space at the center of gravity of the airplane.

Wing sweep can alleviate the congestion somewhat by moving the wing-fuselage juncture forward and perhaps providing thick enough airfoil sections to stow the main gear. Our studies indicate that this compromise does not generally pay off, and that sound, imaginative design can overcome the important congestion problem without resorting to wing sweep.

Crew Compartment Design Difficult and Vital

The second problem we should like to discuss is that of crew compartment design. Layout of comfortable, efficient crew stations is a real art requiring expert attention, even in conventional airplanes. The divided shield concept focuses so much more attention on this arrangement, however, that our former efforts seem almost trivial by comparison. The crux of the whole situation is, of course, the thickness of shielding material distributed on all sides of the crew compartment. Simple geometrical considerations show that every cubic foot of shielded volume costs from 50 to 500 lbs. of shielding. This situation makes it mandatory that every possible effort be made to save every bit of volume not essential. Human engineering to a degree never before necessary is demanded, and equipment refinement and miniaturization of all items which must remain with the crew is of paramount importance. When crew station volumes, including equipment, get down into the range of 50 to 75 cu.ft. per man, apparently simple problems of movement within the compartment and of space to stretch the body to full length are no longer easy. In addition, provision of safe and rapid emergency crew escape is more difficult because of the thick shielding, as well as the restricted space. It is of vital importance that design in this area be done in acute consciousness of the relative value of the pound saved to the unit of human efficiency sacrificed.

One other aspect of crew station design should be pointed out. Nuclear radiation, whether neutrons or gamma rays, is basically directional in nature—that is, if the nuclear airplane were in a vacuum, only a rear face shield would be required at the crew compartment. But, as shown in Fig. 4, the radiation is scattered, or deflected, through angles as high as 180 deg. by hitting atoms in the air, or aircraft structure, so that considerable radiation enters the crew compartment from the sides and from the front. Because the radiation energy decreases as the scattering angle increases, the side radiation is weaker than the direct beam on the rear face, and that hitting the front face of the compartment is weakest of all. Now (Fig. 5) the lower the energy of a given radiation flux, the less

the material thickness required to attenuate it by a given factor. In addition, scattered radiation has to travel a greater distance, from a simple geometrical viewpoint, which leads to a flux decrease inversely proportional to the square of the distance traveled. This situation leads to two interesting conclusions. The crew compartment shielding becomes progressively thinner as one progresses from rear to sides to front, which means that not just cubic feet but the geometrical disposition of the cubic feet is important in optimizing crew station design. Also it is much easier to replace the relatively thin front shielding with transparent materials of equivalent radiation attenuating power than it is to make such a replacement on the sides; the rear face is worse than either sides or front. Thus windows in the crew compartment will likely be nonexistent in the rear face, limited in the sides, and only difficult in the front because of the still-consequential thicknesses of transparent material necessary to replace the more efficient opaque shielding removed.

The directional nature of the radiation leads also to the fact that aircraft structure and components are useful as shielding material, and judicious use of such things as the wing box, landing gear, pay load, and fuel for landing go-arounds can reduce the thickness of shielding required on the crew compartment rear face (Fig. 6). Care must be taken, of course, to account for the expenditure of disposable items in this approach to shield savings.

Structural Relief Not Available

The divided shield concept leads directly to another design situation which is not ideal. We normally think of the fuel and equipment weights carried in a fuselage (Fig. 7) as being rather well distributed along its length. This permits relatively efficient and light fuselage structure and results in reasonable moments of inertia in pitch and yaw and in fairly high frequency fuselage vibration modes. Installation of a heavily shielded crew compartment near the nose of the airplane changes this situation profoundly. A heavier fuselage structure is required for simple static loads, at least. It may be that the dynamic loads arising from the much lower natural frequency in vertical or side bending will lead to further structural increases. The effect of increased moments of inertia in pitch and yaw on the several dynamic stabilities of the airplane will probably not be great (we have not explored this in detail) but they must be considered.

In conventional aircraft, considerable primary wing structural weight is saved by so-called "inertia relief" —that is, any weight items which are installed outboard of the wing root decrease the wing structure necessary to carry a given total airplane gross weight. Virtually all airplanes enjoy some of this saving because of fuel carried in the wing; many have the further advantage of tip or pylon-mounted fuel tanks; wing-mounted power plants, either partially submerged or

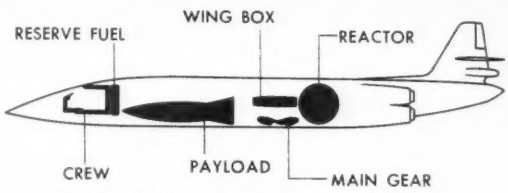

Fig. 6. Equipment and structure as shielding.

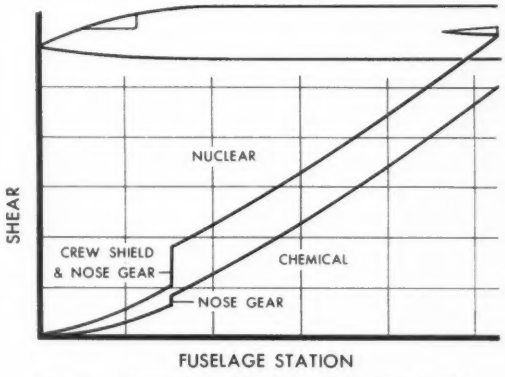

Fig. 7. Comparison of fuselage flight shear loads.

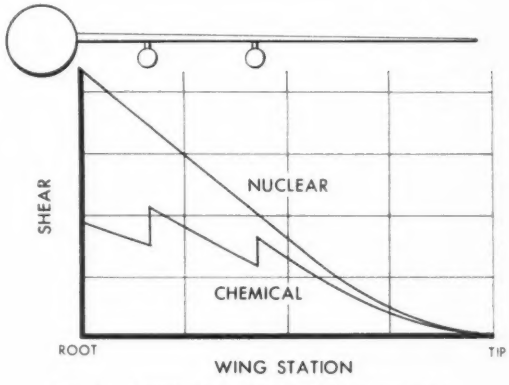

Fig. 8. Comparison of wing flight shear loads.

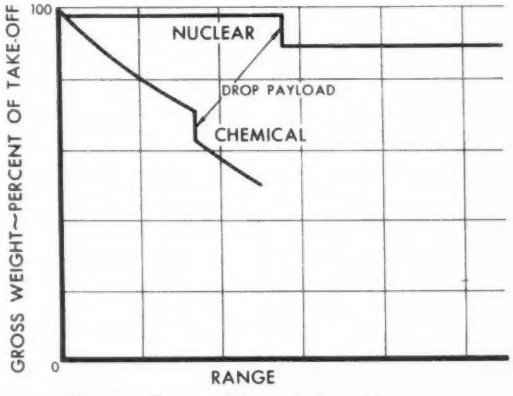

Fig. 9. Gross weight variation with range.

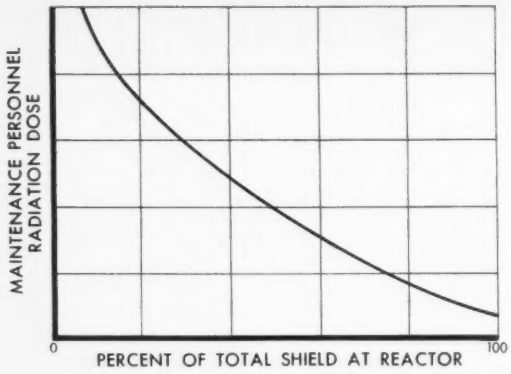

FIG. 10. Shield dividedness effect on ground crew radiation dose.

in strut-mounted nacelles, afford considerable relief; landing gear hung from the wing provides some help; and internal or external wing-mounted armament affords savings. The inertia relief of all of these items is somewhat tempered, of course, by the additional down-bending inertia loads they cause in landing or taxi conditions.

The all-nuclear airplane will probably benefit from few, if any, of these bending reliefs (Fig. 8). The lack of any consequential amount of chemical fuel certainly eliminates aid in that respect. The overriding desirability of having the engines close to the reactor to reduce the heat-transfer problem will most likely keep the engines in the fuselage. If thin, straight wings are used, gear stowage therein is not too attractive. The only bending relief item remaining is armament; some aid may obtain in this direction.

Another type (Fig. 9) of structural relief generally exploited in conventional aircraft is that due to the difference in the maximum gross weight and the landing weight, due mainly to fuel consumed during the mission or, if necessary, dumped prior to landing. Typically the landing gear, after satisfying take-off and taxi load requirements, need be designed for something like half of the maximum gross weight at landing impact. Since the nuclear airplane we are considering uses essentially no fuel during its mission and cannot even be counted on to have disposed of its pay load, no such relief is in sight; the landing gear will have to be designed for the full airplane gross weight.

The last type of weight relief normally exploited in conventional aircraft is the flight performance increase as the gross weight decreases because of fuel consumed during flight. The landing performance is improved by the same gross weight reduction which permitted savings in the landing-gear design. Similarly, maximum speed, cruise speed, rate of climb, and maneuverability all get better during a flight as fuel is consumed. The all-nuclear airplane does not benefit in this fashion and, though the calculation and presentation of nuclear aircraft performance is much simplified, the simplification is at the expense of performance gains at lower gross weights.

Though several of the points discussed so far are outgrowths, to a varying degree, of the radiation from the reactor, let us now consider the effects of this radiation more directly. We shall examine four major problem areas in which the radiation field is the prime factor in reaching certain development decisions:

(1) Crew personnel radiation exposure.
(2) Maintenance personnel radiation exposure.
(3) Air-frame materials damage.
(4) Air-borne equipment integrity of operation.

We believe that we may state without reservation that the flight crew is the single most sensitive element in the air frame from a radiation point of view. Unfortunately the determination of the tolerable human radiation dose is very difficult and may well prove to be one of the most complex research areas in the attainment of operational aircraft. Gamma rays and neutrons of the same intensity damage the body to different degrees, to begin with, and the effects of each of these two types of radiation also vary with the energy of the radiation. As a further complication, various organs of the body are sensitive in varying degrees to radiation, and the effects on these organs become maximum at various times after exposure. Finally, all of the biological reactions are to some degree functions of the dosage rate, the total dose, and the time between exposures. The difficulties faced by the radiobiological people in endeavoring to set up exposure criteria for crew personnel are evident.

Once such criteria are established, however, the shielding engineer and the air-frame designer are just beginning their analysis in order to translate the biological specifications into an operational airplane shield. The combined shielding at the reactor and at the crew station must provide an optimal ratio of neutron to gamma flux inside the crew compartment. Decisions are necessary by the eventual user of the airplane regarding the total number of flight hours desired for an individual crewman, defining the expected time between flights, and stipulating the number of hours per flight. Recognition in all of these respects must be given to the different operational characteristics of the airplane in peacetime training and proficiency flying and in wartime campaign flight. It should be noted here that the separation distance between the reactor and the crew is an important factor in shield design and that it, too, is a variable susceptible to limited control by the designer in the original layout of his airplane. The shielding savings due to increased separation distance must be weighed against the increased fuselage weight and generally unfavorable aerodynamic changes concomitant.

The foregoing discussion of *crew* personnel and radiation leads naturally to that of *ground* personnel and radiation. It is in this regard, we believe, that the largest single penalty of the divided shield concept becomes apparent. It is obvious (Fig. 10) that, if a dosage rate has been established for the flight crew and if a consequential fraction of the total shielding is at the crew station, then the dosage rate everywhere

outside of the crew compartment is much higher than it would be if *all* of the shielding were at the reactor. In other words, any aspect of shield design which takes advantage of the fact that the flight crew is in a restricted, delineated area tends to increase the radiation flux everyplace else.

There are two more aspects of the service and maintenance problem which we will mention before turning to the favorable factors. Because a large percentage of aircraft service and maintenance work is on the power plant, this work will have to be done in an area closer to the reactor than the crew compartment. Also, it will probably not be practical to limit the work of maintenance personnel in accord with a high permissible dosage rate at widely spaced time intervals; they should be able to work at least a half day, 5 days a week, on nuclear airplanes. This means that they will probably be limited to a much smaller dosage rate than will be flight crew, very probably near the present Atomic Energy Commission maximum laboratory dosage rate of 7.5 milliroentgens per hour. Crew dosage rates may be 10 to 100 times this value.

"Dark" Maintenance Situation Lighted by Improvement Factors

The maintenance situation looks very dark, indeed, at this point. Let us examine the factors which improve it.

First, the reactor will not be at full power during service. It will probably be completely shut down. Unfortunately a good deal of decaying radioactivity remains even in this state, but the decrease compared to full power is greater than one order of magnitude.

Second, it is probably not desirable or necessary to initiate service immediately after shutdown; since the radioactivity remaining is decaying with time, a wait of a few hours decreases the dosage rate. Along these same general lines, the flux after shutdown is almost exclusively gamma rays, which simplifies the problem somewhat.

A third aid in the maintenance picture is the possibility of removing from the reactor some of the radioactive materials after shutdown. The degree to which this may be accomplished is unalterably defined by the structure and design of the specific reactor, but some cases hold considerable promise of flux reductions by one or two orders of magnitude.

The last recognized means of achieving normal, manual power-plant service is through the use of a technique known as "shield augmentation." Since neutron emission is not a postshutdown problem and since the reactor neutron shield might conceivably be a liquid, it is possible to consider draining or removing the neutron shield and replacing it with a high density liquid or slurry having much better gamma attenuation characteristics. Flux reduction by better than an order of magnitude is certainly possible if the mechanical difficulties can be overcome.

We have so far carefully avoided mentioning the use of remotely controlled handling devices for service and maintenance. We believe that some simple operations can be performed by manipulators of one kind or another—for example, accomplishment of several of the flux reduction means we have discussed would require such an approach. But for plain, everyday, operationally practical upkeep of air frames, power plants, and equipment, it is next to impossible to replace the two hands and the Mark I eyeball of a mechanic with steel claws and a TV tube. We have endeavored to quantify this statement, and it appears that something between 5 and 10 times the number of manhours is required to accomplish typical service work by manipulators *with direct vision* as is required with a conventional manual contact approach. Let us qualify these remarks to a limited extent; there will certainly be a number of areas where adjustments and checks must be made either before or after shutdown and ground-safing. It will be of paramount importance for the air-frame designer to provide for these procedures in such a fashion that manipulators can be used as efficiently as possible. In the event that the reactor can in no way be rendered ground-safe, it will be necessary to remove the power plant *in toto* to special maintenance shops for its service, at the same time making the rest of the airplane accessible to normal service operations. In this case the design of the power plant for manipulator maintenance, even in special shop areas, will be a supreme test of the power-plant designer's skill.

We have discussed the biological damage of nuclear radiation and its impact on many aspects of aircraft design. A simpler, more easily tested, and probably not quite so profoundly damaging characteristic of radiation is in the materials of which airplanes are made. A really thorough assessment of the problem is beyond the scope of this paper; many of the basic mechanisms of radiation damage are not yet fully understood by even the metallurgists and physicists. In addition, material damage *outside* of the reactor is serious, in general, to the degree to which the divided shield concept is exploited. Thus the trend toward more shielding at the reactor, suggested by service and maintenance considerations, aids radiation damage reduction similarly.

Material Radiation Damage May Prove Significant

The fields in which radiation damage may prove significant are at least eight. They are not listed in any particular order because their relative occurrence, and the degree to which the individual effects are important, vary with the flux level and type, the material being considered, and the use intended for the material in the airplane. As we will see, only a few of these should prove important and only a couple will be vital.

The first field, *dimensional changes*, refers to changes occurring without regard to stress on the subject part.

The total integrated dosage required to cause significant change is such that only materials inside the reactor shield itself could conceivably be affected. It is thus very improbable that the air-frame designer need consider this.

The second item, *creep acceleration*, is, in the purest sense, of interest primarily as a dimensional change. As in the first item we mentioned, creep acceleration will be most critical inside the reactor, but it may also prove to be somewhat troublesome in some instances in the air frame. It appears that some materials undergo considerable creep acceleration at high stress levels and/or high temperatures due to radiation. Certainly in supersonic aircraft with significant aerodynamic heating of structures and even in subsonic airplanes having prestressed connectors, it will be necessary for the designer to account carefully for potential radiation-accelerated creep characteristics.

Our third category, *hardness, strength, embrittlement increases*, may prove quite important. Fortunately, work-hardenable alloys in the hard condition are not further hardened appreciably. Nevertheless, for fittings and connectors near the reactor, the possibilities of increases in stress concentration and notch sensitivity and decrease in impact strength will require consideration, as will the effects on fatigue life.

Our fourth and fifth terms, *accelerated diffusion at faying surfaces* and *accelerated stress corrosion*, spring from a single characteristic of radiation—it accelerates diffusion of atoms in a metal. Plated pistons and riveted or bolted connections where dissimilar metals rub may, through microdiffusion across the plane of contact, lead to embrittlement or other important metallurgical changes. Accelerated stress corrosion is probably much more serious a problem in the reactor, but reactor attachment fittings and support structure may require some consideration in this respect.

The sixth item, *transmutation*, is included mainly for completeness. It is certainly true that, under slow neutron irradiation, most metals gradually transmute into others. For example, aluminum becomes silicon, and copper becomes nickel and zinc. Some of the metals become isotopes of the original element, but none of the common structural materials is transmuted into liquids or gases and, even more important, the percentage of the original metal converted in an airplane lifetime is probably less than the percentage of unknown impurities in the original material. Thus transmutation is not expected to be recognized in the air-frame design.

Induced radioactivity, the seventh category, appears to be one of the most important in the entire list. In general, the material being bombarded by neutrons must have four characteristics for it to be critical in this regard.

(1) It must exhibit a fairly high tendency to capture neutrons within its nucleus.

(2) The isotope resulting from this capture must be unstable—that is, radioactive.

(3) The radiation emitted from the isotope must include a consequential amount of medium- or high-energy gamma rays.

(4) The half-life of the isotope must be significantly long.

Speaking loosely, it is the product of these factors which is important; a material deficient in one respect may be so high in another that it remains on the critical list. Fortunately such materials as aluminum, iron, titanium, and magnesium are markedly deficient in at least one of the criteria. Cobalt, zinc, tungsten, manganese, chromium, and molybdenum, on the other hand, are somewhat discouraging, to various degrees. In general it appears that it is not the fundamental element of common materials but their alloying constituents which are most troublesome. No matter how the lists of good, intermediate, and bad materials finally end up in detail, it is obvious that accurate material quality control, not only of alloying elements but also of impurities, will be of sharply increased significance. The designer will have to become fairly conversant with induced radioactivity characteristics and will have to keep his material specifications within the bounds prescribed to keep the air frame from becoming too hot to handle.

We have saved *molecular structure changes* until last because they are characteristic of mainly organic materials, and organics, in turn, respond to irradiation in mainly this fashion. Peculiarly enough, either of two opposite effects predominates in organics in this regard. In most cases the basic molecular chains are broken, resulting usually in poorer physical characteristics, often in gas evolution, and eventually in destruction of the material as a usable component. In a few cases the opposite occurs: the basic molecular chains cross-link themselves without cleaving, and the result is greater strength and density and generally improved physical characteristics, particularly heat stability. Most of our typical aircraft organics—such as rubber, lubricating oils, fuels, hydraulic fluids, electric insulations and dielectrics, and the transparent butyrates and polyesters—are hurt to one degree or another by radiation. Rubbers lose elasticity; lubricants, fuels, and hydraulic fluids evolve gas and tend to gum; and the transparent plastics weaken and discolor. Fortunately, the majority of these materials will probably last through one or more overhaul periods. In the particular case of organic fluids, some latitude of choice is possible in selecting materials inherently better than others, and the use of additives can be helpful in promoting radiation stability. But again, as with metals and alloys, a whole new additional criterion of material selection must be learned and applied if sound aircraft design is to accrue.

Electronic Equipment May Suffer Serious Effects

We have hinted at changes in dielectric properties of materials previously. If we view electronic equip-

ment operating in a radiation field, we find that even more serious effects may be expected. Perhaps the most serious is the possibility that the ionized sphere of air surrounding the airplane and centered at the reactor may attenuate electromagnetic propagation. If this proves to be true, then radio transmission and reception in the airplane would be adversely affected, and, even more critical, radar ranges would be reduced. These phenomena would occur, of course, only to the degree that the flux level outside the reactor is high, and tendencies toward greater reactor shielding would reduce this type of deterioration of equipment performance. It is still not known whether or not this attenuation occurs at all frequencies, however, or, if it does, what the threshold ionization level for detectable attenuation is at the various frequencies.

The effect of the radiation on electronic components is better known today. Four known types which become essentially unusable in high radiation fluxes are germanium transistors, electrolytic condensers, phototubes, and bias cells. These are all replaceable by other types which appear to be quite satisfactory even under long, fairly intense irradiation. But induced radioactivity again assumes considerable importance in that, for example, capacitors, relay and switch contacts, and vacuum tubes become radioactive fairly readily, and a cooling-off period of several weeks before handling such components would create a pretty difficult service problem in the aircraft electronic systems. Considerable relief in all these respects is potentially available to the aircraft designer through placement of the electronics gear far from the reactor and by locating it in the radiation shadow of some mass in the airplane. Some of the reactor and engine controls, however, will undoubtedly incorporate electronic elements of necessity close to the reactor, and these will not be so easily rendered satisfactory.

Three other equipment problems should be mentioned here. Relay and switch contacts wear faster in the ionized air of a radiation field, and photographic film fogs very quickly in even modest fluxes. Ozone, a product of air ionization, hastens the deterioration of rubber.

Viewing the equipment problem in general, it is seen that a majority of the work to be done in improving components is outside of the control of the air-frame designer, but he can, by efficient arrangement of his layouts, ease the radiation level to which much of the equipment is subjected by as much as two to four orders of magnitude; his potential contribution in this respect should certainly be recognized early in the equipment development program.

We mentioned earlier the likelihood that the nuclear engines would be kept close to the reactor and, therefore, that wing-mounted engines would probably not be available for wing bending relief. For the sake of completeness, the other implications of not hanging the engines on the wing should be mentioned. By scrutinizing the reputed and real advantages of wing-mounted engines, we can quickly see what design problems may accrue if wing mounting is not feasible. The oldest reasons for wing engines are the requirements of propeller clearance and some reduction in fuselage vibration. Neither of these is particularly applicable to a nuclear-powered turbojet airplane, though the clearance problem would be if nuclear turboprops are considered. The attainment of good turbojet inlet ram recovery is always simpler with nacelle inlets, and the difficulties of jet exhaust washing the aft fuselage are automatically eliminated. Both of these problems can be solved with fuselage installations, but more design attention is required.

Main landing-gear stowage often works out very nicely in engine nacelles but can be handled in the fuselage or wing root. The absence of cutouts in the wing for gear stowage is of consequential advantage in attaining high torsional stiffness. Maintenance accessibility of wing nacelles is *inherently* better than that of engines submerged in a fuselage, but the differences can be made slight by good design. Engine fires in the air or explosive failure of a turbojet are *intrinsically* somewhat better isolated in individual nacelles, but there are many sound design approaches to equal or better the situation with submerged power plants. The newest advantage of wing engines is the use of the engine mass to aid in increasing critical wing flutter speeds. This is mostly applicable to swept wings of high aspect ratio and is thus not necessarily appropriate to most of the configurations likely in the nuclear bomber.

Some of the problems created by locating the engines in the fuselage are real, some are academic. In general, we are confident that the advantages of such an installation far outweigh the advantages of wing mounting, particularly in the case of the nuclear airplane.

Challenge to Designers Seen in Need for Cooling Apparatus

In the design of today's turbojet aircraft we have gotten far away from the cooling radiator problems of the old liquid-cooled reciprocating engine. It appears that, with nuclear power, we will have to brush up on this skill. Some of the potential nuclear cycle candidates have radiators in the turbojets, but these are outside of the direct responsibility of the air-frame designer. We refer, instead, to the fact that at least the shield, and possibly some of the other reactor components, may require cooling through the use of a relatively conventional liquid-to-air heat exchanger. The amount of heat to be handled may approach 10 per cent of the total reactor power. Incorporation of a cooling system of this capacity in a high-speed airplane with only nominal weight cost and reasonable drag penalties is a great challenge to the designer and thermodynamicist and requires extreme integration of the air-frame and power-plant design effort.

Another cooling problem is inherent in reactors of all varieties. When a reactor is shut down, though the

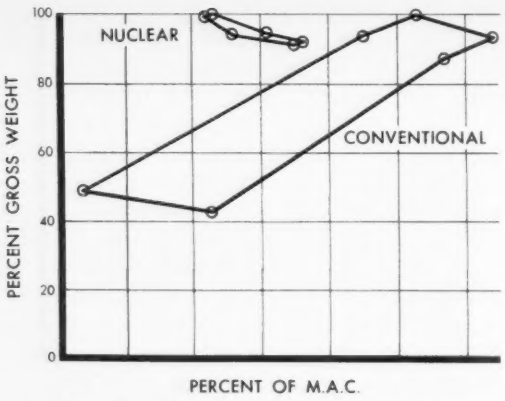

FIG. 11. Comparison of balance diagrams.

fission process stops, considerable heat continues to be generated by the decay of the fission products. This phenomenon, known as "afterheat," decays with time, but the amount of heat during the first week or two is great enough to require forced cooling to avoid having the core melt itself and destroy the reactor. The situation leads to one easy and one difficult problem. Following a normal landing, either an engine must be run continuously to remove the afterheat, an auxiliary air supply must be attached, or the reactor fuel must be removed. In the event of a crash or an accident during take-off or landing which stops all engines, the afterheat is certainly going to damage the core.

The last design problem created by the nuclear power plant is one of the potential, not certain, type. It is possible that the response characteristics of the reactor to increased or decreased power demand, either inherently or because of limitations built in for safety, will be slow compared to those desired during take-off or landing. Solution to such a difficulty intimately involves both the power-plant and the air-frame manufacturer and should be thoroughly analyzed by them quite early in the development of the power plant and air frame.

We have now completed a discussion of the design problems expected to result inherently from the application of nuclear power plants to useful aircraft. We are sure that many of those apparent difficulties looming as most serious now will prove to be most tractable to handle; we are equally sure that some of the most innocent will prove to be real backbreakers. In any event, let us proceed to a survey of the air-frame design *advantages* which we may reasonably expect to accrue with our nuclear power plant. Because discussion of *new* problems is inherently more interesting and stimulating than discussion of *ex*-problems, we will treat the advantages very briefly.

We shall only mention the salient advantage of increased endurance, or range, since it has been so frequently extolled in every discussion of nuclear-powered aircraft. We will see a little later, however, that this lack of endurance sensitivity implies some very definite secondary attributes to be enjoyed in actual airplane design and construction.

One of the immediate enjoyable prospects following removal of chemical fuel from an airplane is the reduced center-of-gravity travel to be expected (Fig. 11). Though some c.g. movement will remain, associated with the armament, pay load, gear position, and crew, the net result should be a reduction of travel from the typical 12 or 16 per cent to half that or less. This has one significant effect—the tail volume may be reduced consequentially. This is brought about, of course, because all of the critical longitudinal trim moment changes are reduced, and the overall tail moment envelope required becomes accordingly smaller.

Another very real advantage having to do with center of gravity and trim problems arises from the divided shielding concept. Even if the most-rearward c.g. limit is held closely during design, it usually tends to drift aft as soon as the airplane gets into service and modifications commence; often the compromises necessary to handle the problem are very undesirable. In the nuclear aircraft a new means of compensating for this is available. If the shield dividedness is such that small changes in dividedness cause very small changes in total shielding weight, as is expected to be the case, then it will be possible to increase slightly the shield on the rear crew compartment face and decrease the reactor shadow shield thickness. This is a powerful tool for changing balance, particularly in the terminal phase of project design, and is almost free weightwise. We might add that, if the accuracy of the science of shielding computation does not improve considerably before we design the first airplane, we are going to be in real unknown weight and balance troubles in even the design stage!

You will recall that we discussed the lack of wing inertia relief at some length when we considered the disadvantages imposed by the nuclear power plant. The removal of the inertia relief items from the wing provides, however, modest compensation. In essence, the wing structure becomes much simpler, cleaner, and more efficient because the compromises in structural arrangement and design for fuel stowage and engine mounting need not be made. Whereas it has been in the past fairly easy to provide access doors in the multirib structural box of thick, low-speed wings, it cannot be done cheaply, weightwise, in thin multispar, high-speed wings. Thus a consequential weight-saving accrues because the nuclear airplane does not need the internal wing access.

We mentioned earlier that if wing sweep is not used, the area around the airplane center of gravity will likely be somewhat congested by the necessity of locating the wing box, landing gear, and nuclear power plant close to the c.g. Again the congestion problem is not all bad in that the major load paths from the gear to the power plant and from the wing to the power plant will be very short. This leads to greater structural efficiency and reduces the weight of heavy structure required to carry the power-plant load to the wing and main landing gear

Cost of an Extra Pound Not so Great

If one views the conventional chemical airplane as being built up of completely linear components—that is, if engines, air-frame equipment, and air-frames are all rubber so that they can grow or shrink to match perfectly any change in gross weight and size to maintain airplane *performance* constant—then the addition or subtraction of a pound of weight causes a substantially greater change in the total aircraft gross weight. Since such component flexibility is not generally available *in fact* except in the air frame itself—wing area, for example—the cost of added weight normally results mainly in a penalty in some phases of aircraft performance. But the best real measure of the penalty is still obtained by assessing the gross weight increase on a "rubber" airplane. In chemically powered aircraft the gross weight cost for a pound of added weight may be anything from 3 to 10 lbs. This is obviously a seriously large ratio, and a major portion of it is generated by the extra fuel and associated system provisions necessary to keep speed, rate-of-climb, and range characteristics constant.

The all-nuclear-powered aircraft enjoys a marked advantage in this respect. Though its engines and reactor, its landing gear and equipment, and its air-frame structure must go up somewhat in weight, as do the same elements of the chemical airplane, the net increase is considerably less, particularly when the mission incorporates a sizable endurance requirement. It appears that the weight-increase ratio may vary between 1.5 and 4, rather than 3 to 10.

If the situation is cast in terms of real, rather than rubber, airplanes, a similar advantage accrues. The chemical version will suffer a modest decrease in speed and climb performance and a more serious decrease in range. The nuclear airplane will lose speed and climb performance only. This entire reassessment of the cost of a pound will no doubt have a marked effect on the criteria applied to deciding the wisdom of equipment addition to nuclear aircraft.

We should mention, before leaving this particular subject completely, that the real cost of a pound of additional drag is susceptible to the same analysis and gives the same results. This is of particular importance:

(1) When equipment protruding into the airstream is added, or when the aerodynamic airplane is modified for new equipment or,

(2) If the original estimates of airplane drag prove to be lower than the drag actually encountered.

By far the predominant factor in the vulnerability of chemically powered aircraft to nonexplosive bullets, to shrapnel and debris, and to small explosive shells is the fuel system. It achieves this dubious eminence because not only is a square foot of fuel more sensitive to projectiles than all other aircraft elements excepting personnel but also there are many times more square feet of fuel than of any other component or system. In addition the fuel system has the further unfortunate characteristic of spreading damage by fire quickly and extensively; it thus generates by its inherent qualities a continuing, multiplying source of damage to other systems in the airplane.

The all-nuclear airplane has an obvious and tremendous superiority in this respect. The reactor itself may prove to be somewhat vulnerable, but its vulnerable area is relatively small and the net gain from elimination of large fuel capacity will be enormous. It should be noted here that engine fire hazards in noncombat operation of conventional aircraft are great because of the fuel-loaded plumbing, pumps, and controls adjacent to the engine. If chemical fuel is used only for take-off and landing in the nuclear airplane, the entire system near the engines can be purged and rendered inert during nearly all of the mission.

In addition to the reduction of fuel system and power-plant vulnerability is that associated with the crew. The rather thick layers of shielding surrounding the crew compartment will likely protect the personnel almost completely from fragments and small projectiles, particularly those approaching from the sides, top and bottom, and aft.

For the sake of fairness we should mention that the nuclear airplane does not have any particular advantage against *large* explosive warheads. These are designed to cripple air-frame structure *wherever* they hit, and no outstanding differences may be expected between chemical and nuclear airplanes, with the possible exception of the crew station area where the shielding may be of some help.

Endurance Advantage Outweighs All New Problems

Viewing the comments we have made, both good and bad, now in retrospect, it would appear that the aircraft designer is to be faced with many more new problems than he is to be relieved of old ones. This is most assuredly the case if we count only the *numbers* of problems on each side. If we consider *both* quantity and quality of the advantages and disadvantages, ignoring the flight endurance advantage, we will again come out on the short end as designers. But the importance—the quality—of the endurance characteristic is such as to dominate completely this apparent negative balance and render it unimportant. And this unique characteristic is one to be greeted enthusiastically, not by the designer alone, but also by the military analyst, the military operating command, and the aircraft crew. Clever, creative aircraft design will remain the *sine qua non*, as it has been in the past, if we are to exploit the nuclear power-plant application to the fullest.

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Flutter Model Testing at Transonic Speeds†

Flutter research on reflection plane models of straight, swept, and delta wings in a 3 × 4 ft. transonic test facility.

Introduction

As the speed of flight has increased to supersonic velocities, the problems in determining the aeroelastic integrity of aircraft have multiplied. In the transonic regime, particularly, the theoretical prediction of the flutter characteristics of a specific configuration is extremely difficult and often impossible. It is not surprising, therefore, that wind-tunnel flutter model testing has become a necessary and common tool for use in design of prototype aircraft.

A fundamental requirement of flutter model test data which are to be used for application to full-scale aircraft is that the model density ratio μ be of a magnitude comparable to that of the full-scale article. In transonic wind-tunnel facilities in which the desired Mach Number range can be obtained only at much reduced densities, very lightweight models must be used to obtain these proper values of μ. The necessity of concomitantly obtaining satisfactory elastic properties indicates a further requirement for a high stiffness-to-weight ratio.

The Cornell Aeronautical Laboratory, Inc., under sponsorship of the Dynamics Branch, Aircraft Laboratory, of the WADC, has been conducting flutter research on reflection plane models of straight, swept, and delta wings in the C.A.L. 3 × 4 ft. transonic test facility (Fig. 1). This tunnel required that tests at transonic Mach Numbers be conducted at below atmospheric densities. A search for a satisfactory model resulted in techniques of model construction and testing which are believed to have wide application. Because of the present great interest in flutter model testing, this

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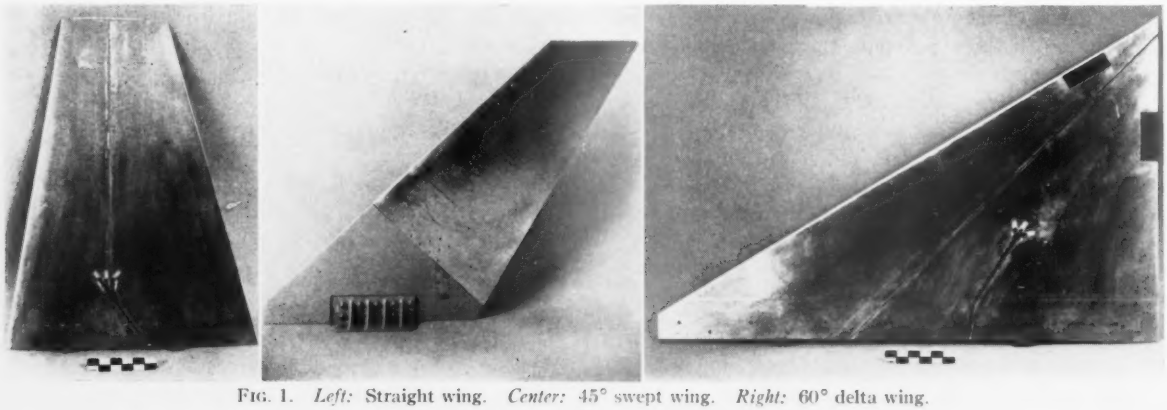

Fig. 1. *Left:* Straight wing. *Center:* 45° swept wing. *Right:* 60° delta wing.

TABLE 1
Core Material Properties

Properties	Material	
	Styrofoam*	Strux*
Density, lb./ft.^{3}	4.3–4.7	6–7
Tensile strength, psi	170–185	170
Shear strength, psi	80–95	125–140
Compressive strength, psi	120–140 (Yield)	125 (Ult.)
Bending strength, psi	150–170	147
Elastic modulus, psi	2,400–2,700	5,500
Temperature limit, °F.	175	350
Moisture absorption	None	Negligible
Machinability	Good	Good

* Trade names.

information is reported in the hope that it will be of value and help to the aircraft industry.

Design Concepts

The basic requirement that the model have a low weight-to-stiffness ratio indicated the desirability of full monocoque-type construction. Using this type of construction, we found that proper model weight and rigidity required the use of aluminum skins of the order of 0.001 to 0.006 in. in thickness. With such foil material, the concept of employing ribs, stringers, and spars for skin stabilization is clearly inadequate. The foil skins must be stabilized against buckling over the entire surface area of the model, and thus solid core sandwich construction was indicated.

The core material must be of minimum weight with closely controlled average density. Ideally it should provide no bending or torsional rigidity to the model yet should be sufficiently strong in shear to prevent buckling of the skins. Furthermore, it must act as a carrier for internal ballast weights and other extra parts. Fortunately, there are commercially available foam plastics which satisfy these requirements. The properties of two such materials, which have been used at C.A.L., are listed in Table 1.

Some mention must be made regarding the desirability of using a balsa wood core rather than one made of plastic. Actually in some earlier models balsa was employed but was discarded for the following reasons: anisotropy, variations in properties, too great contributions to stiffness, low strain allowables, and too large density. For an earlier program involving tests at high subsonic speeds, balsa was used in a layer between a plastic core and the dural skin. This procedure was employed because, at the time, we had no satisfactory technique for bonding the plastic to the dural. These models proved quite satisfactory for their purposes. However, the undesirability of the low strain allowable of the balsa was clearly indicated when, on a static test specimen used to determine maximum deflection and limit load, the skin buckled well below its yield strength because of failure of the balsa layer.

A further problem in building a model of this type is the joining of the skin to the core material with a satisfactory bond. Initial experiments indicated that even carefully controlled glue lines resulted in total glue line weight of the order of as much as 25 per cent of total model weight. While this is not necessarily an excessive weight penalty, it does indicate the requirement for complete knowledge of the weight distribution of the glue line or, in effect, the requirement of a perfectly uniform glue line, within engineering accuracy. Furthermore, the hardness of the foil skins which are obtained by rolling heavier sheet down to the required thickness makes preparation of the skins to receive the bond a critical item. By a purely empirical means, commercially available priming and adhesive agents were discovered which, by their combined actions, gave satisfactory bond of the aluminum skins to the plastic core.

Model Construction Techniques

The foam plastic material used for the model cores is received from the manufacturer in the form of rectangular slabs. Ordinary wood working tools are used to process these to the final form. The first operation is to trim the slab to the plan form and airfoil section of the desired wing model and attach it to its root fitting.

Next, a template of the "developed" skin surface is laid over a strip of aluminum foil of the design thickness, and a matching section of foil is cut out with a sharp knife. The surface of the foil is now roughened carefully, by employing finishing sandpaper with an extremely fine grit, and then chemically cleaned and dried. A phenolic base primer is baked on the skin followed by a coat of air-drying primer. (Two primers are used because it was found that the first only adhered well to the aluminum while the second only adhered well to the bonding agent. However, the mutual adhesion of the two agents is excellent.)

In preparing the adhesive, ordinary cheesecloth is attached to a wooden frame and laid over a sheet of cellophane on a flat surface. An epoxy resin is brushed in a thin coat over the cheesecloth. A second sheet of cellophane is then laid over the frame and cheesecloth, and, by use of a doctoring blade, excess adhesive is worked to the sides until a uniform coating is obtained. After removal of the cellophane, satisfactory preparation is indicated if all the holes in the cheesecloth are open with only the saturated threads retaining adhesive. The treated cheesecloth is then cut from the frame and wrapped carefully around the core. This is covered by the skin in which the leading edge has been preformed. A coarse fibered cloth is placed over the skin, and the assembly is inserted into a sheet plastic bag which is then sealed. A vacuum pump is attached and the bag evacuated to provide at least 10 psi bonding pressure. After several hours, the model is removed and the excess skin trimmed off.

With this technique uniform bond weights of about 0.0002 lbs. per sq.in. of surface are obtained. In special cases, where desired, through the repeated use of more than one set of cellophane sheets, satisfactory bonds with weights as low as 0.00013 lbs. per sq.in. have been obtained.

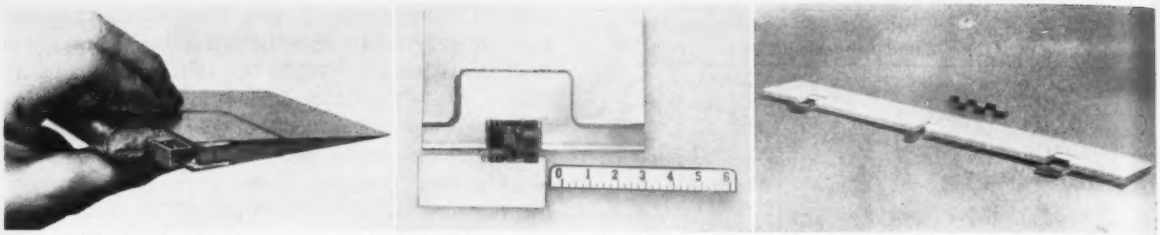

FIG. 2. (a) *Left:* Model aileron; cross section of completed aileron. (b) *Center:* Model aileron; spring and flexure pivot attachment of aileron, cover plates removed. (c) *Right:* Model aileron; core and dural fittings.

When internal ballast weights or fittings are to be used, they are incorporated in the models before finish machining of the foam plastic core. For example, suppose it is desired to add two spanwise strips equally spaced from the unballasted model c.g. at a distance equal to the unballasted radius of gyration. (This increases the model's weight, unbalance, and moment of inertia in such a manner that an increase in tunnel test density results in no change in any of the nondimensional mass parameters.) In this case the leading and trailing edges of the core are sliced off along the desired percentage chord lines. Thin grooves are machined into the four mating surfaces at the chord plane. The lead strips are inserted in the grooves with a press fit, and then the mating surfaces are glued back together again with an ordinary animal glue and the finish machining is performed.

Fig. 2(a) shows a section of a model aileron in which a dural insert has been placed to distribute loads, from flexure pivots and springs [Fig. 2(b)], to the skins.

As noted above, in many cases the skins are designed to slip on the core from the leading edge. Sometimes it is more desirable to form a very sharp trailing edge and slip on the skin from the aft end. In these cases an additional piece of skin is wrapped around the leading edge. The aileron is of this construction [Fig. 2(a)].

The above comments should indicate that this is a very flexible operation, like a child playing with a piece of clay. It may be poked and pulled at will. If a doubler is needed here or an external store fitting is needed there, no very special considerations need be made—just cut a little hole in the core and glue in what you will.

STATIC TESTS

As these models are highly flexible, dial gages are not used for measuring their static deflections under load because of the changing spring loads introduced by the gages themselves. Instead, measurements are made of the distance between an accurately fixed reference plane and the deflected model using a depth micrometer.

Originally a commercial depth gage was used. To prevent the micrometer from loading the model, initial contact completed an electrical circuit consisting of the wing, the reference plane, the depth gage, a battery, and a sensitive ammeter. A large resistance was also included in the circuit so that even for very light contact between the micrometer probe and the model, the surface contact resistance was small in comparison. With this system, repeatable data accurate to 0.0005 in. are obtained.

When a great many data points were desired this method was too time consuming. A servodriven depth gage was developed with which the deflections could be more rapidly measured (Fig. 3). When the probe is not in contact with the model it hangs below the balance point of the linear differential transformer (a). The induced signal in the transformer passes through a suitable electrical network and directs the motor (b) to drive the screw (c) until the probe comes in contact with the model. Once contact has been made, the rod moves relative to the screw until it reaches the balance point of the differential transformer, whereupon the motor stops. The location of the model is measured in terms of revolutions of the Veeder counter with a resultant accuracy of 0.0005 in. Since the force on the model due to the probe is approximately 0.008 lbs. and is independent of model deflection, errors in measurement resulting from the weight of the probe are negligible.

This servodriven depth gage was used to obtain the influence coefficients of a 60° delta wing model. The

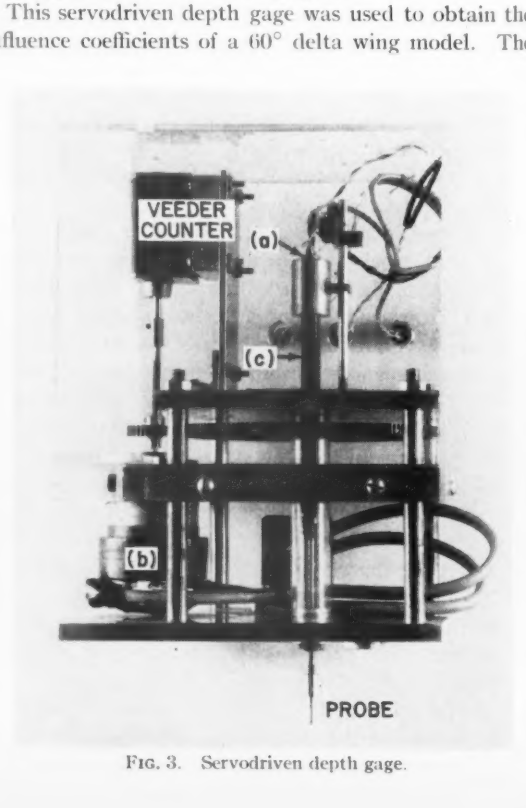

FIG. 3. Servodriven depth gage.

wing was mounted horizontally with a reference plane mounted above it. To attach the loading pan to the wing surface, small wooden blocks were bonded to the underside of the wing at the 24 control stations that were used for this surface. The influence coefficients were obtained by applying five increments of increasing and decreasing load at one station and measuring deflections at another of the 24 stations. This procedure was repeated 576 times to obtain a full set of influence coefficients. It was found that, with the use of the servo-driven depth gage, the 24 influence coefficients over the surface of the wing could be obtained relatively easily and accurately. If a great deal of such work was to be done, however, it would be desirable to manufacture a number of the servounits and employ them simultaneously.

Vibration Tests

In planning the first vibration tests on these models it was decided, a priori, that physical attachment of even the smallest vibration generator would seriously compromise the validity of the test results. Instead, acoustically forced vibration is obtained by using a plate, 8 in. in diameter, attached to the top of a Calidyne Model 6 shaker and placed near the surface of the flutter model with about a 1-in. air gap between plate and model. The air gap acts as a very soft spring, and ample force is transmitted to excite the model in all of its normal modes that are of interest, up to 250 cps.

Tests were made in the C.A.L. altitude chamber to determine the aerodynamic apparent mass for certain models. Even at air densities equivalent to a 50,000-ft. altitude, the acoustic vibration excitor proved satisfactory. The "sand pattern" technique was used for obtaining node lines.

Flutter Tests

To date over 50 of these models have been built and tested—all of them in the C.A.L. 3 × 4 ft. porous wall wind tunnel. This variable density tunnel had an available Mach Number range of from 0 to 1.25 with the higher Mach Number points being obtainable only at substantially reduced densities. The tunnel had three independent controls: impeller blade angle on the main drive, r.p.m. of the compressors providing porous wall suction, and pumps and valves which fixed the mass of air in the closed circuit tunnel. Test section dynamic pressure and static density were primarily functions of these three variables. The 8 × 8 ft. transonic wind tunnel now in operation at C.A.L. has similar operating characteristics and controls.

Fig. 4 indicates how hypothetical stability boundary for a wing flutter model would be obtained. Starting with "wind-off" at some reduced pressure in the tunnel, point 1 on Fig. 4, the tunnel speed would be increased, with tunnel conditions following along a constant mass line. This "trajectory" intersects a desired μ line at a speed, point 2, below the estimated flutter velocity. Now, by successively bleeding air into the tunnel and increasing air speed, a zig-zag path is followed up the constant μ line until flutter is obtained, point 3.

If the model were not lost at the flutter point, after data were taken the air speed would be reduced quickly, as shown by the trajectory to point 4. Now, air would be pumped out of the tunnel shell, extending the trajectory to point 5 and then the entire procedure repeated. In this fashion the entire boundary may be delineated. Such a boundary could well be used to set placard limits for an actual aircraft as each point on the boundary is easily convertible for plotting in altitude - Mach Number coordinates.

For research purposes, such a boundary is insufficient if it is desired to determine separately the effects of

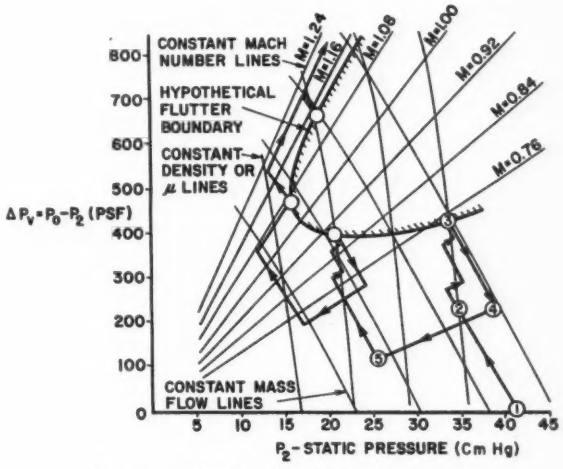

Fig. 4. Determination of flutter boundary.

Mach Number and mass density μ. By testing a series of dynamically similar models of differing rigidities and weights, a series of such boundaries is obtained, and, by cross-plotting the resultant data, the desired information is obtainable.

According to simple theory, the flutter speed is proportional to the product of the wing torsional frequency times the square root of the mass density ratio, $V \propto \omega_\alpha \sqrt{\mu}$. But ω_α is proportional to the square root of the ratio of the torsional rigidity to the weight, $\omega_\alpha \propto \sqrt{GJ/W}$. The mass ratio is proportional to the ratio of the weight to the air density, $\mu = W/\rho$. It is seen that $V \propto \sqrt{GJ/\rho}$. Thus it might be expected that a change only in model rigidity would move the stability boundary along constant Mach Number lines until corresponding points on the boundary would be at the proper new values of ρ. A change only in a model weight should not affect the boundary. From this simple point of view it would seem that only one boundary need be obtained to provide all required data. Actual variation from this theory is classified.[1] However, the theory does permit us to see that by proper ballasting and stiffening we can make a model that will flutter at any desired Mach Number and at any desired μ.

Because of their expendable nature, instrumentation

of the models was restricted to the use of resistance wire strain gages. Rosettes were mounted on the models to indicate bending and torsional strain. They were used primarily for the determination of frequencies, but an indication of relative magnitude of the bending and torsional motion was also obtained. The signals from the strain gages were recorded accurately at each data point on an oscillograph with high-frequency galvanometers but were also fed to a direct inking oscillograph. The latter was a Brush recorder modified to accept 1,200 ft. rolls of paper. It ran continuously during a test and was the primary monitor of approach to flutter. A direct reading frequency meter also was proved of value in conducting the tests. Lastly, a tape recorder with a 1-min. tape loop constantly recorded the signals so that, if flutter suddenly occurred and destroyed the model before data could be taken on the oscillograph, an accurate permanent record could still be made by the tape playback.

Results

It has been found from wind-tunnel tests on more than 50 of these models that the construction method is excellent for use in flutter model testing. The models are inexpensive. All structural rigidity is in the skins and design calculations of rigidities, and frequencies made on this predication have been experimentally authenticated. Structural damping of the models is low, of the order of 0.01–0.02. They are durable and rugged and can carry loads up to and beyond the yield point of the skins without buckling or failure of the bond or core. They can withstand the buffeting of transonic testing and the vibration of near flutter conditions for hours at a time without exhibiting any change in dynamic properties. They are frangible and do no damage to the wind tunnel upon failure. They permit actual scaling of full-size aircraft surfaces because of the ability to use very thin gage materials and because internal airplane structure can easily be modeled and imbedded in the core.

The testing technique employed, whereby control of density variation in the tunnel is made to take an active part not only in the obtainment of several flutter points with a single model but also in varying model scale during test, greatly expand the value of a single experiment. The weight and stiffness of the models employed need not be restricted to extremely narrow limits but may vary over relatively wide ranges. The combination of these controls of tunnel conditions and model properties permits the obtainment of flutter data anywhere within the tunnel operating range of Mach Numbers at almost any desired model mass ratio. Independent control of density and air speed, furthermore, permits approaching the flutter boundary, or line of zero damping, along the gradient of lines of constant damping. This makes for the most accurate determination of the flutter point.

Reference

[1] *Transonic Flutter Model Tests* (unclassified title), WADC Tech. Report 56-214 (to be published):

Part I: Maier, Henry G., and King, Stephen R., *45 Degree Swept Wings*, November, 1956 (confidential report).

Part II: Brady, W. Gordon, King, Stephen R., and Maier, Henry G., *Straight Wings*, December, 1956 (confidential report).

Part III: Balcerak, John C., and Ostaszewski Nicholas H., *Delta Wings*, December, 1956 (confidential report).

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Errata

Two errors have been noted in the paper, "A Model Atmosphere for Widespread Precipitation," by David Atlas and Edwin Kessler, III, published in the Aeronautical Engineering Review, Vol. 16, No. 2, February, 1957.

Eq. 7, page 72, should read: $D_0 = 0.09R^{0.21}$.

Fig. 6, page 72, label to abscissa of inset figure, should read: MED. VOL. DIAM. - D_0 - (mm).

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Optimum Thrust Programing for High-Altitude Rockets

A discussion of the problem of establishing the thrust-time relation which will achieve the optimum compromise between reduction in gravity and drag losses and thereby result in minimum fuel expenditure.

Introduction

One of the most important exterior ballistic problems associated with high-altitude rocketry is that of carrying a specified pay load to a desired height most economically—i.e., with minimum expenditure of fuel. The two main deterrents to achieving altitude are the forces of gravity and aerodynamic drag, both of which diminish with increasing altitude. Unfortunately, the requirements for reducing the deterrent effects of gravity and drag are antithetical. Gravity losses are proportional to flight time whereas drag losses are proportional to some power of the velocity. Thus, diminution of gravity losses requires a short flight time—i.e., a high velocity—whereas reduction of drag losses calls for low velocity. One of the problems which confronts the designer of a high-altitude rocket, then, is the establishment of an optimum thrust program—the thrust-time relation which will achieve the optimum compromise between reduction in gravity and drag losses and thereby result in minimum fuel expenditure.

The American rocket pioneer R. H. Goddard in his paper "A Method of Reaching Extreme Altitudes"[1] was first in calling attention to the problem of thrust programing. For purposes of mathematical analysis, Goddard considered an idealized rocket—namely, a right circular cone, pay load at the tip, and casing which drops away continuously (with zero velocity with respect to the remaining rocket) as the burning surface recedes (see Fig. 1). Goddard inferred the existence of a solution to his problem from the following argument: "If, at any intermediate altitude, the velocity of ascent be very great, the air resistance (depending on the square of the velocity) will also be very great. On the other hand, if the velocity of ascent be very small, force will be required to overcome gravity for a long period of time. In both cases the mass necessary to be expelled will be excessively large. Evidently, then, the velocity of ascent must have a special value at each point in space." Goddard went on to state that the determination of the necessary velocity-time function presents a new and unsolved problem in the calculus of variations. Consequently, he abandoned a rigorous approach and constructed an approximate, numerical solution. Almost a decade after the publication (1919) of Goddard's classical paper, Hamel,[2] in a very brief publication, objected to the lack of rigor in Goddard's analysis and pointed out the existence of a solution by means of the calculus

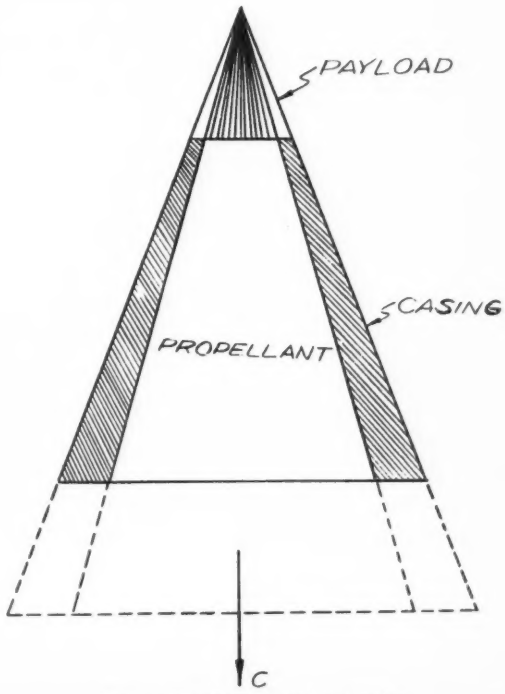

Fig. 1. Goddard's idealized rocket.

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of variations. More recently, other workers—e.g., Tsien and Evans,[3] Lawden,[4] and Leitmann[5,6]—have derived necessary conditions for the existence of minimum initial mass of a rocket required to transport a given burnout mass to specified altitude.

Theory

Let m be the mass of the rocket and s the altitude at time t. A dot will denote differentiation with respect to time. It is assumed that the aerodynamic drag D is a function of s and $\dot{s}$ only. The effective exhaust velocity c and the acceleration of gravity g are taken as constant. (Taking account of the change of g with altitude modifies the form of the solution slightly.[6]) Conditions at the outset of powered flight, $t = 0$, will be denoted by subscript zero; conditions at burnout, $t = t_1$, by subscript one. Symbols + and − attached to the subscripts will denote conditions at the instant succeeding $t = 0$ and preceding $t = t_1$, respectively. Coordinate $s(t)$ is assumed continuous over the whole trajectory. Functions $\dot{s}(t)$ and $m(t)$ are taken continuous over the interval $0 < t \leq t_1$. The discontinuity of $\dot{s}$ and m at $t = 0$—i.e., impulsive boosting at launch—is permitted. (As a matter of fact, it will be shown that impulsive boosting is a requirement of the solution.) At the outset of powered flight, $t = 0$, $s = s_0 = 0$, $\dot{s} = \dot{s}_0 = 0$, and $m = m_0$. After initial impulsive boosting, $s = s_{0+} = s_0 = 0$ still, but $\dot{s} = \dot{s}_{0+}$ and $m = m_{0+}$. At burnout, $t = t_{1-}$, $s = s_{1-} = s_1$, $\dot{s} = \dot{s}_{1-} = \dot{s}_1$, and $m = m_{1-} = m_1$ (these functions being assumed continuous). However, the acceleration $\ddot{s}$ and the mass-flow rate $\dot{m}$ are not assumed continuous at burnout. Thus, at $t = t_{1-}$, $\ddot{s} = \ddot{s}_{1-}$ and $\dot{m} = \dot{m}_{1-}$. At the outset of coasting flight, $t = t_1$, $\ddot{s} = \ddot{s}_1$, and $\dot{m} = \dot{m}_1 = 0$.

The equation of rocket motion for vertical flight, neglecting earth's rotation and taking account of drag and gravity forces only, is

$$c\dot{m} + (\ddot{s} + g)m + D(s, \dot{s}) = 0 \tag{1}$$

Integration of Eq. (1) over the initial boost period δ, where $\delta \to 0$, is

$$m_0 = m_{0+} \exp\,(\dot{s}_{0+}/c) \tag{2}$$

The equation of coasting flight is merely Eq. (1) with $\dot{m} = 0$ (no thrust).

The problem is then: Given m_1, c, g, and the function $D(s, \dot{s})$, what is the function $s(t)$ in order that the rocket reach summit altitude S with minimum initial mass m_0? Integration of the equation of coasting flight between $s = s_1$ and $s = S$ ($\dot{s} = \dot{s}_1$ and $\dot{s} = 0$) yields a relation between s_1 and $\dot{s}_1$ symbolized by

$$\dot{s}_1 = \phi(s_1) \tag{3}$$

By means of the calculus of variations it can be shown that the following relations must be satisfied in order that m_0 be a minimum. Throughout powered flight, $0 < t < t_1$,

$$\epsilon \equiv \frac{\partial D}{\partial s} - \left(\ddot{s}\,\frac{\partial^2 D}{\partial \dot{s}^2} + \dot{s}\,\frac{\partial^2 D}{\partial s \partial \dot{s}} + \frac{\dot{s}}{c}\,\frac{\partial D}{\partial s} + \frac{2\ddot{s} + g}{c}\,\frac{\partial D}{\partial \dot{s}} + \frac{\ddot{s} + g}{c^2}\,D \right) = 0 \tag{4}$$

At burnout, $t = t_{1-}$,

$$\dot{s}_1[(\partial D/\partial \dot{s}) + (D/c)]_{t=t_1} = m_1 g + D(s_1, \dot{s}_1) \tag{5}$$

The problem of determining the optimum solution, the function $s(t)$ which corresponds to a stationary value of m_0, is then determinate. Eqs. (3) and (5) may be solved for s_1 and $\dot{s}_1$. Eq. (4) is a second-order differential equation in $s(t)$ for whose integration s_1 and $\dot{s}_1$ constitute initial values. Upon integration of Eq. (4) over $0 < t < t_1$, the values of t_1 and $\dot{s}_{0+}$ are obtained. Eq. (1) can then be integrated to give m_{0+}—i.e.,

$$m_{0+} = \exp\left(-\frac{\dot{s}_{0+}}{c}\right)\left[\int_{0+}^{t_1} \frac{D}{c} \exp\left(\frac{\dot{s} + gt}{c}\right) dt + m_1 \exp\left(\frac{\dot{s}_1 + gt_1}{c}\right)\right] \tag{6}$$

The value of initial rocket mass m_0 is now found from Eq. (2). The acceleration $\ddot{s}$ can be determined from Eq. (4), whereupon Eq. (1) yields the thrust

$$T = -c\dot{m} = m(\ddot{s} + g) + D \tag{7}$$

It is easy to show[6] that Eq. (4) possesses a first integral

$$I \equiv \left[mg + D - \dot{s}\left(\frac{\partial D}{\partial \dot{s}} + \frac{D}{c}\right)\right] \exp\left(\frac{\dot{s} + gt}{c}\right) = 0 \tag{8}$$

Eq. (8) leads to the immediate conclusion that $\dot{s}$ cannot vanish in the interval $0 < t < t_1$. Since $D = 0$ when $\dot{s} = 0$, but $mg \neq 0$, it follows that $\dot{s} \neq 0$. Hence $\dot{s}_{0+} \neq 0$, and impulsive boosting is always required.

Special Case

It is customary to express the aerodynamic drag force in the form

$$D = (1/2)\rho a C_D \dot{s}^2 \tag{9}$$

where

ρ = air density
a = reference area
C_D = drag coefficient

The air density ρ is essentially a function of altitude s. The drag coefficient C_D is a function of Mach and Reynolds Numbers and is therefore a function of both altitude and velocity. A simple, idealized expression for drag results when C_D is taken as constant. A fair approximation to ρ is an exponential in s. With these assumptions

$$D = W \exp\,(-\alpha s)\dot{s}^2 \tag{10}$$

where

W = $(1/2)a\rho_0 C_D$
ρ_0 = sea-level air density
α = constant

If the expression for drag given by Eq. (1) is used, Eq. (4) becomes

$$\frac{\ddot{s}}{g} = \frac{V[V^2 + (1-\beta)V - 2\beta]}{\beta[V^2 + 4V + 2]} \tag{11}$$

where $V = \dot{s}/c, \qquad \beta = g/\alpha c^2$

Eq. (11) may be integrated for $s(V)$ and $t(V)$—i.e.,

$$\alpha s = V - V_{0+} + \frac{\gamma}{2} \ln \frac{2V + (1-\beta) - \gamma}{2V + (1-\beta) + \gamma} \times \frac{2V_{0+} + (1-\beta) + \gamma}{2V_{0+} + (1-\beta) - \gamma} + \frac{3+\beta}{2} \ln \frac{V^2 + (1-\beta)V - 2\beta}{V_{0+}^2 + (1-\beta)V_{0+} - 2\beta} \tag{12}$$

$$\frac{gt}{c} = \ln \frac{V_{0+}}{V} + \frac{\gamma}{2} \ln \frac{2V + (1-\beta) - \gamma}{2V + (1-\beta) + \gamma} \times \frac{2V_{0+} + (1-\beta) + \gamma}{2V_{0+} + (1-\beta) - \gamma} + \frac{1+\beta}{2} \ln \frac{V^2 + (1-\beta)V - 2\beta}{V_{0+}^2 + (1-\beta)V_{0+} - 2\beta} \tag{13}$$

where $\gamma = \sqrt{(1-\beta)^2 + 8\beta}$

Substitution of Eqs. (12) and (13) in the integrated form of Eq. (1) results in

$$M = \frac{m}{m_1} = \exp\left(-V - \frac{gt}{c}\right)\left\{\frac{Wc^2}{m_1 g}\beta V_{0+} \times \exp(V_{0+})\,[V_{0+}^2 + (1-\beta)V_{0+} - 2\beta] \times \left[\frac{V+2}{V^2 + (1-\beta)V - 2\beta} - \frac{V_1 + 2}{V_1^2 + (1-\beta)V_1 - 2\beta}\right] + \exp\left(V_1 + \frac{gt_1}{c}\right)\right\} \tag{14}$$

The thrust is then given by

$$\frac{T}{m_1 g} = \frac{Wc^2}{m_1 g} V^2 \exp(-\alpha s) + \frac{m}{m_1}\left(1 + \frac{\ddot{s}}{g}\right) \tag{15}$$

Eq. (3) takes the form

$$V_1^2 = -2\beta \exp\left(2\beta \frac{Wc^2}{m_1 g} x_1\right) \times \int_{x_1}^{x_2} \exp\left(-2\beta \frac{Wc^2}{m_1 g} x\right) \frac{dx}{x} \tag{16}$$

where

$$x_1 = \exp(-\alpha s_1), \qquad x_2 = \exp(-\alpha S)$$

The integral of Eq. (16) may be evaluated by means of the tabulated integral[7]

$$Ei(-y) = -\int_y^\infty \frac{\exp(-z)}{z}\, dz$$

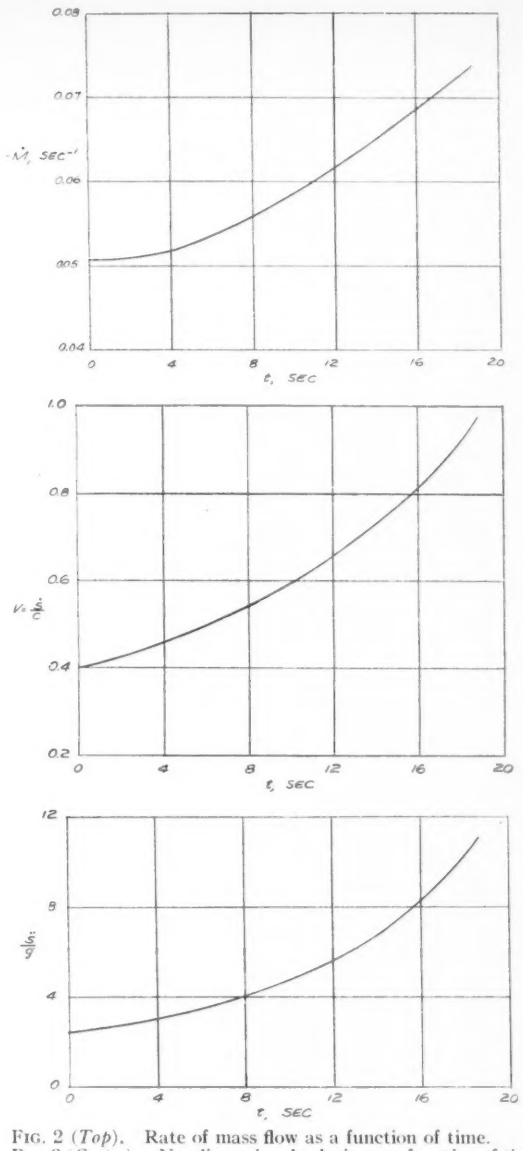

FIG. 2 (*Top*). Rate of mass flow as a function of time.
FIG. 3 (*Center*). Nondimensional velocity as a function of time.
FIG. 4 (*Bottom*). Acceleration as a function of time.

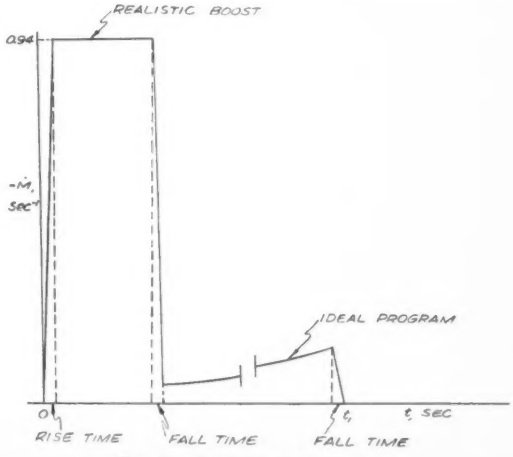

FIG. 5. Realistic thrust program.

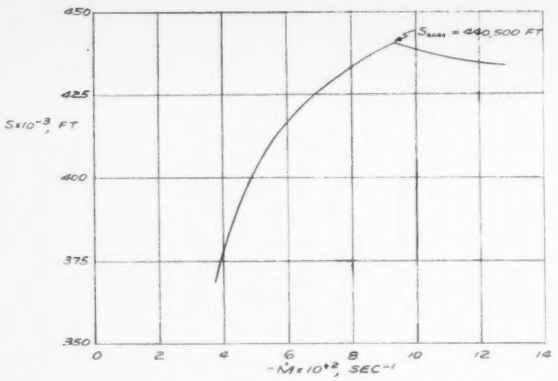

FIG. 6. Summit altitude as a function of mass-flow rate—constant thrust.

or from the series solution

$$\int \exp(-bx)\frac{dx}{x} = \ln|x| - \frac{bx}{1\cdot 1!} + \frac{(bx)^2}{2\cdot 2!} - \cdots$$

Finally, Eq. (5) becomes

$$(Wc^2/m_1g)\ V_1^2(1 + V_1) = \exp(\alpha s_1) \qquad (17)$$

The solution proceeds as follows: (a) Solve Eqs. (16) and (17) for s_1 and V_1; (b) substitute s_1 and V_1 for s and V, respectively, in Eq. (12) and solve for V_{0+}; (c) using this value of V_{0+} and setting $V = V_1$ in Eq. (13) yield t_1; (d) Eq. (14) then gives $m(V)$, and Eq. (15) with Eq. (11) is used to find $T(V)$. Since $t(V)$ is known, m and T can be expressed as functions of time t.

Numerical Example

Consider a rocket of the following characteristics:

$$W/m_1 = 10^{-5}\text{ ft.}, \qquad c = 5{,}500\text{ ft./sec.}$$

required to reach a summit altitude

$$S = 92.6\text{ miles} = 488{,}950\text{ ft.}$$

with minimum fuel expenditure. Also

$$\alpha = 22{,}000\text{ ft.}^{-1}, \qquad g = 32.2\text{ ft./sec.}^2$$

Applying the equations of the preceding section results in

$$s_1 = 62{,}576\text{ ft.}, \qquad \dot{s}_1 = 5{,}308\text{ ft./sec.}$$
$$t_1 = 18.7\text{ sec.}, \qquad \dot{s}_{0+} = 2{,}199\text{ ft./sec.}$$
$$m_{0+}/m_1 = 2.10, \qquad m_0/m_1 = 3.14$$

The normalized mass-flow rate $M = \dot{m}/m_1$, velocity $V = \dot{s}/c$, and acceleration $\ddot{s}/g$ are shown as functions of time in Figs. 2–4. The idealized thrust program requires the attainment of an initial velocity of 2,199 ft./sec. by means of an impulsive boost. In practice, the initial impulsive boost can be approximated by a short phase of high thrust. Thereafter, the ideal thrust program may be followed. To investigate the effect on summit altitude of replacing the ideal, impulsive boost by a realistic, high-thrust phase, consider the application of a constant, high thrust of duration 1.2 sec. during which the same amount of fuel, $m_0 - m_{0+}$, is consumed as in the ideal boost. Thereafter, burning proceeds according to program. Account is also taken of the finite time to build up and drop the thrust, with 0.1 sec. as the rise- and fall-times. The mass-flow rate for the high-thrust phase is quite attainable. For example, if the rocket under consideration has a burnout mass, m_1, of 10 slugs, the booster thrust is 51,700 lbs. Fig. 5 illustrates this realistic thrust program. For comparison, consider also the effect on summit altitude of keeping the thrust constant throughout burning (see Fig. 6). Integration of the equations of motion was carried out on an IBM 701 digital computer. The following summit altitudes resulted:

Thrust	Summit Altitude
Ideal program	488,950 ft.
Realistic program	471,680 ft.
Best constant thrust	440,500 ft.

Thus there is a loss of about 3.5 per cent in summit altitude in going from ideal to realistic thrust program. A further decrease of about 6.6 per cent in summit altitude is experienced when thrust is held constant at its best value.

Conclusion

It seems reasonable to conclude that the ideal thrust program can be approximated by a realistic one—one with a high-thrust phase in place of impulsive boost—without greatly affecting summit altitude. Whether or not the added complexity of controlling the thrust is worth the gain over best constant thrust is a problem which can only be answered in particular cases.

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An aircraft crashes. Twenty-two of 38 aboard perish, eleven when catapulted against seat backs not "crash safety designed." That incident, and others related in this paper, show how biomechanical investigation and analyses of survivable-type accidents can save lives.

Greater Safety Through Crash Injury Analyses†

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Introduction

THE BIOMECHANICAL ANALYSES of aircraft accidents—in relation to crash injuries and their causes—can aid in improving aviation safety. As we all know, the objective of aviation safety is twofold. The first and most important is the protection of human life; the second is the protection of property. In civil aviation, the achievement of this objective also permits, from an economic point of view, profitable enterprise—if all other factors are amenable. In military aviation, the achievement of safety also results in economy for the taxpaper in peacetime and his welfare in time of war.

Until recent years, the attainment of operational safety in aviation has been sought through accident prevention—by the elimination of causation factors brought to light by accident investigation and analysis.

This approach is logical since its successful attainment achieves both phases of the objective—namely, the preservation of life and property.

Those who have dedicated themselves to accident prevention deserve high praise for the fine safety record which we now enjoy. And certainly it should be noted here that the success of these accident prevention groups has been the result of the cooperation of many specialists, including accident analysts and statisticians.

However, despite the continued efforts of these dedicated groups, none of us is so naive as to believe that we can prevent *all* accidents—unless we keep our aircraft on the ground. As we put more aircraft into the air—saturating the facilities of our airports, our airways, and our traffic control systems—we can expect some accidents to occur. Too, we may be fast approaching the point of diminishing return on the curve of accident prevention measured in manpower vs. accident reduction. In other words, we are faced with the fact that some accidents will continue to occur despite all practicable efforts to prevent such unfortunate incidents.

FIG. 1. Spear-like, steel tube uprights of aircraft seats (arrow) proved fatal to eleven of 22 air travelers killed in a single accident.

Single Crash in 1958 May Cost 227 Lives

If this premise is true, we must then recognize the fact that accidents involving civil jet transport will

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expose more people per aircraft, per accident, than are exposed in the DC-3, CV-240, and DC-4 types of aircraft whose maximum capacities range from 21 to 50 people.

Some of our civil jet aircraft flying in 1958 will be carrying 227 people per airplane. This is almost six times the number of persons carried in our present CV-240 type of aircraft.

If we accept the premise that a certain proportion of future accidents will be survivable in nature and if we give heed to the large numbers of people who may be exposed to injury and death in these survivable accidents, we find justification for expanding our efforts beyond accident prevention—to include crash injury prevention. This is an approach which can improve our safety record even though we cannot prevent all accidents.

The preservation of life through the prevention of injury in survivable-type accidents is a logical and integral part of aviation safety for it achieves the primary objective of aviation safety. The prevention of damage to the aircraft and to property, from an economic point of view, is secondary. If this concept is accepted, our safety record can be improved merely by turning part of our attention and our known methods of accident investigation and analysis to the field of crash injury investigation, analyses, and engineering.

Concept Requires Only an Extension of Effort

Crash injury and survival investigation and analyses require no greater attention to detail nor a higher level of objective thinking than does the investigation and analysis of causation factors which contribute to the occurrence of accidents. The only difference between accident prevention analysis and injury prevention analysis is the added—basic—consideration of the type and site of injuries sustained and the relationships between the injuries and their mechanical and force causes. Nor does crash injury investigation and analysis require any special breed of investigator for it utilizes the same men (and experience) normally used in accident investigation—the pilot, the engineer, and the doctor, as well as the analyst and the statistician. Neither does injury prevention work require a different mode of thinking; it merely needs a few additional questions inserted in the accident investigation picture. For example, what were the injuries and what were the objects, or design criteria, which contributed to injury; or on the other hand, what criteria contributed to survival? Thus, merely by extending our investigative experience and the perimeters of our analyses and questioning, we can integrate crash injury and crash survival investigation with our present safety work.

Injuries (in survivable conditions), like accidents, are often caused by minor deficiencies which, through a chain of circumstances, sometimes emerge into catastrophic events. An accident, for example, can be caused by improper retention of an electric wire, which through chafing causes a short circuit, ultimately resulting in a prop reversal; if this occurs on take-off, a catastrophic accident may result.

The causes of injury in survivable-type accidents are also often caused by so-called minor details or deficiencies of design or of maintenance. The improper locking of a seat attachment, for example, can result in the seat tearing free and catapulting itself against other seats, causing a landslide of seats (and passengers) against the forward bulkhead. Or, the design of the seat may not be compatible with the design of the floor, permitting undue flexion to be imposed on the seat attachments during a hard belly landing—resulting in failure of passenger tie-down and fatality. In other cases, loss of life or the occurrence of dangerous injury may be indirectly due to a lack of design knowledge concerning crash loads which occur in survivable accidents. These and other factors affecting survival can be ascertained by the integration of crash injury investigation within the present framework of accident investigation.

Too Much, Too Little Strength Equally Fatal

A few examples of crash injury information extracted from survivable accidents are as follows:

(1) In some survivable accidents the hat-rack structure causes severe and sometimes fatal head injuries when it is pushed down on top of the seats and passengers. *Reason:* The hat rack was too rigid and too firmly attached to the fuselage.

(2) In another accident, all of the occupied seats were stripped out of the intact portion of the cabin, leaving the floor in an undamaged condition and causing a high proportion of fatalities due to inadequate flexion strength in the seat-attachment units.

(3) In another crash, in which 22 of the 38 passengers died, crash injury investigation and analysis showed that eleven died solely of head injuries directly attributable to a particular design of the seat back, which had a fixed recline lock and no break-over feature. The spear-like steel tube uprights (Fig. 1) in the seat backs punctured the occupants' skulls. The relationship of the injuries to the steel tube uprights was found by analysis of medical and autopsy data including photographs of the injuries, the shape of the steel tubes, and many other details such as the direction in which the occupants' heads were propelled during the crash.

Biomechanical analysis of crash injury factors need not only confine itself to the association of injuries with their direct design causes; helpful design criteria can also be obtained by analyzing the accident from another point of view—i.e., "What injuries did not occur which one would normally expect to have occurred in this accident?" Often an accident involving severe crash force will result in an unexpected lack of serious injuries. If no planned, crash survival design or extra safety equipment (crash helmets, etc.) are apparent in the aircraft, the lack of injury may be traced to good, but inadvertent, crash safety design—design which could be incorporated in future aircraft.

In another accident, involving a light plane, the sole

occupant survived with very little injury to the head and chest even though the aircraft struck the ground in an absolute vertical (nose-down) attitude at an impact speed in excess of 90 m.p.h. The calculated, mean deceleration was in the order of 55*g*—exerting a load equal to more than 4 tons on the pilot. The pilot's lack of serious injuries is interesting in that he was *not* wearing shoulder harness or a crash helmet; in addition, his "2,000-lb." safety belt failed, but he sustained no internal injuries.

Yielding Structure Saved This Pilot's Life

In an accident such as this, fatality would be the normal expectation; if not fatality, severe head and chest injuries would surely be expected. Analyses of why such injuries did not occur showed that the pilot's head and chest struck the lightweight (ductile) metal structure of which the instrument panel and upper cowling were constructed. Yielding of this structure spread the crash load over a broad area of his head and chest. In addition, there was a relatively clear space of approximately 1 ft. between the instrument panel and the firewall; this permitted some forward displacement of the panel, as well as rearward movement of the firewall and engine thereby saving the pilot's chest from being crushed.

In another accident, involving a military fixed-wing trainer, the control stick failed at its lower attachment point during impact, probably due to a blow from the pilot's chest; no chest injury, however, was sustained—apparently because the attachment failed at a lesser load than that necessary to cause chest injury. If the design criteria for this stick attachment were incorporated in other aircraft, we might expect a lower incidence of chest injuries from striking the control stick.

In a recent helicopter accident, analysis showed that the vertical, mean deceleration could not have been less than 28*g*. Generally, spinal injury would be a normal result of such a crash load. Surprisingly, however, no spinal injury was sustained by either of the two survivors. This lack of spinal injury is important when it is realized that the dynamic (peak) vertical load probably was in excess of 50*g*. The question then arises, "What condition or design prevented spinal injury?" A preliminary analysis of the accident-injury data indicates that two factors may have been responsible:

(1) The jackknifed position of the occupants at the time the principal crash force was imposed, resulting in the load acting "transversely" to the spinal column.

(2) The plastic yielding of the metal seat pans which apparently spread the load over a wide area of the buttocks and also absorbed energy.

These data, when completed, may be useful to engineers concerned with the design of ejection seats.

Similar data from other accidents, through crash injury investigation and biomechanical analyses, can eventually provide engineers with design perimeters useful in attaining greater crash safety—if it is presented properly.

Naturally, this qualitative information, as well as quantitative (statistical) data, must be presented in a meaningful way so that the accident-injury data are in a usable form for the engineer. Previously used classifications of accident damage and severity of injury leave much to be desired in this particular work. For this reason a special code has been developed, tested, and used by Av-CIR with success. Essentially, this classification code covers three primary areas:

(1) Six degrees of incident condition (angle and velocity of impact, etc.).

(2) Six degrees of impact damage to the inhabitable areas of the aircraft.

(3) Ten degrees of injury, of which four concern the seriousness of fatality.

Comparison, Evaluation Point to Improvements

This code permits a comparison of the severity of the incident, the severity of impact damage, and the resulting severity of injury, thereby allowing a logical evaluation of crash injury conditions and the design improvements which should be pursued.

The universal use of a "measuring," or evaluation, code such as this, in combination with the biomechanical analysis of survivable-type accidents, can produce information of vital use to the design engineer for the preservation of human life in future accidents.

Conclusions

To sum up:

(1) The first objective of aviation safety is the preservation of human life; the second is the preservation of property.

(2) The realistic application of accident prevention methods will prevent most accidents, but not all.

(3) Of those accidents that will occur, some will be survivable in nature.

(4) Jet transports, because of their size, will expose a greater number of people to injury, per accident.

(5) To provide reasonable crash protection for these persons, as well as for occupants of smaller aircraft, it is imperative that the precepts of crash injury investigation and analysis (and injury prevention through design) be integrated to the fullest extent practicable in aviation safety programs.

▲ ▲ ▲

Grover Loening*

Air Freight in Competition With Motor Transport

"If we can build a 20,000-lb. pay-load cargo airplane, with a 350 m.p.h. cruising speed and a 35 m.p.h. or less landing speed, in quantity, for about $300,000, we can put motor transport out of business at its own price."

Introduction

There was a revolution in transport not long after the building of the pyramids in Egypt. Until then the great cargo operations by the engineers who built those monstrous monuments consisted of moving almost everything on skids, with an incredible amount of manpower to move the loads. Then gradually through a few ensuing centuries we come to the later Greek and then the Roman operations when the wheel came into wide use. It may appear to be stretching things a bit to bring out this revolution in transportation now, but we are on the threshold of a new era where a similar kind of fundamental change is apt to take place.

Surface transport of people and cargo requires surface facilities that are becoming increasingly expensive—roads, bridges, viaducts, etc. All these transportation facilities not only require construction and maintenance but are also, now, extremely vulnerable in time of war. Water transportation in canals and even in rivers is also vulnerable and requires maintenance. Water transportation in the open sea is, of course, not so vulnerable, but it is the slowest of all means of transport.

Meanwhile, in the last 50 years, we have discovered the air road—conquered and started to use this road for worldwide transportation—a road that is indestructible, leads everywhere, and requires no expense and maintenance except at terminals.

In the last two decades the world has been rather startled by—and is still trying to digest—the breathless way in which air transport of people has grown and will obviously continue to grow. The billions of passenger-miles that are now piled up each year were little dreamed of two or three decades ago, and we are evidently caught unprepared for its impact on our lives.

But the use of this free and open air road for transportation in carrying cargoes has, as we all know, been little exploited to any degree until the last few years. The possibilities appear so immense that we can well ponder whether the progress in means of transport from skids to wheels at the time of the Egyptian is not about to see the next step from wheels to wings within our coming generation. We know one thing—that every time we seriously get at any phase of load carrying by air, even the most optimistic of us is startled to find how easy and practical it is.

The delays in acceptance of movement of cargo by air in great quantities have been caused chiefly by misconceptions—not only in the mind of the public but even in the minds of many technicians. Up to as recently as 1940 when the author and others presented various papers, statistics, and estimates of what could be done, there was a general and stupid conviction that the desirable freight plane should be a large, slow, voluminous affair with little regard to streamline shape. In other words, there was at that time, and there still is, a prevalent failure to understand that the economy of freight transportation by air is largely dependent for success upon the highest speed for air-freight carriers. The ton-miles per year are much more important than the tons carried per trip! And speed gives the quick turnaround, leading to the many more trips that pile up the ton-miles per year.

We have already seen today how large tonnages of cargo can be effectively carried. World War II, the Korean war operations, and the Berlin air lift opened our eyes. But we see little of commercial air-cargo carrying in comparison to the cargo tonnages carried by truck, rail, and water.

Our future concepts of what air transport can do in the cargo field to replace wheel vehicles can best be guided now by a preliminary look at how air-freight transport would compare in competition with motor transport. Are we going to give wings to the trailer truck? Let us take a look and see what we are up against.

The Truck Business

The United States economy is expanding, and so is the motor transport business. There are some 10,000,000 trucks in use in the United States. Truck transporta-

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tion employs over 6,000,000 people, and the production of trucks is at a rate of about 1,000,000 new units a year—almost more than the rest of the world put together. In this production over half is in light trucks (below 10,000 lbs. gross weight), but in the heavy trailer trucks the production is in the neighborhood of 100,000 units a year.

The total transportation of cargoes in the United States in all forms of transportation amounts to some 1.2 trillion ton-miles a year and is steadily increasing so that by 1975 the total is likely to have doubled to about 2 trillion ton-miles. Of this total, 10 years ago the railroads carried 66 per cent. They have now decreased to about 48 per cent. During these last 10 years trucking ton-mileage has increased from 9 to well over 20 per cent of this total.

Meanwhile, to put it in its proper insignificant place, air-cargo carrying amounts to about 1/20th of 1 per cent of the total.

Parallel with the enormous growth of trucking transportation, there can be noted the tendency of new industrial plants to locate near highways rather than near railroads. This truck-freight traffic growth has closely followed the geographical dispersion of industry, particularly the growth of the South and the West where rail services were limited. All shippers have found, of course, that the flexibility for the small shipment that trucking provides is a great advantage—and that the door-to-door delivery is a tremendous convenience. Ten years ago trucking moved about 80 billion ton-miles of cargo, and in this last year the volume has exceeded 270 billion so that this field has more than tripled in 10 years.

The average length of haul in interstate common carrier trucking has increased from 177 miles in 1945 to almost 300 miles in 1956. Of course, some regions of the country like the Rocky Mountain area have much longer hauls with an average of 700 miles. What is of great interest to us in the air business is that the increase in activities between manufacturing areas in the North and customers in Florida, as well as the increased activity shipping commodities and manufactures from Florida to customers in the North, has caused a great increase in nonstop truck operations—for example, between Miami and New York and even, for that matter, between Miami and Atlanta.

The trailer truck takes a load from New York on a Monday evening and delivers in Miami the following Thursday morning—if everything goes well and if the weather is favorable (and weather is very important in trucking—icy roads, fog, etc.). This fast schedule is not always met. Atlanta is supposed to be 24 hours shorter than this, but from neither of these points, to cite examples, can delivery be made without keeping the material in transit, idle, under insurance, and shaken to pieces for at least 1 to 3 hauling days.

The best and newest types of trailer trucks—which we should use in our comparison—are known as the Hi-Cube type with a volume of about 1,800 cu.ft. and a load capacity averaging 20,000 to 25,000 lbs. Such an output will cost in the neighborhood of $30,000 when completely equipped with the most modern facilities, including air conditioning, etc.

Such a unit under the highest utilization will run about 100,000 miles a year, and therefore will have a capacity in the neighborhood of 1,000,000 ton-miles a year. The average charge for transportation of this kind will run around 5 cents a ton-mile. These trailer units will run about 3 to 4 miles per gallon of gas.

Trucking is faced with somewhat the same condition as air cargo as far as utilization is concerned. The hours of use a year include many runs empty. Incidentally, neither the trucking companies nor the Government keep accurate statistics that would allow us to gather the average utilization of capacity to determine the load factor. In the country-wide operation of trucking, general freight accounts for 48 per cent of the total, liquid petroleum 24, motor vehicles 5, building material 3, and miscellaneous merchandise 16. The average trailer truck needs relief drivers so that each trailer needs a minimum of two, and as many as four, men for the 100,000-miles-a-year operation.

Average figures obtainable from the trucking industry indicate that heavy trailers will average around 500,000 ton-miles a year so that industry average load factor is around 50 per cent—which for cargo business is quite high.

Although trucking statistics are not too reliable or in agreement, it would appear that there are some 500,000 heavy trailer trucks in actual operation in the United States. Over 9,000,000 remaining registered trucks are largely of the light and medium variety. This enormous amount of equipment is indeed extremely impressive when one realizes that only 50 years ago there were only 700 trucks of all sizes in the United States.

The Possible Cargo Airplane Business

At the present time, the air-cargo business looks like a sick newborn infant when we contemplate the above figures of the motor transport industry. As of last year, the entire air-cargo fleet in the United States consisted of 119 planes, 86 of which were all cargo carriers and 33 of which were combination carriers (cargo and passenger). In addition to this there were some 22 large four-engined cargo planes on order, some of which have, no doubt, been delivered. This fleet turned in for the year 1956 a total volume in business including mail (which is included in comparable truck statistics) of 472,000,000 ton-miles a year in domestic service. Of this total, 129,000,000 were delivered by the strictly all cargo air lines, and 343,000,000 were delivered by the domestic trunk lines which operate both cargo planes and combination carriers. The bulk of the long-distance cargo operation is for distances of 600 miles where an overnight early morning delivery can be done by air so effectively, in comparison with any other means of transport, including time for pickup and delivery.

Although these totals of air cargo are a minute fraction of cargo movements in this country, they have grown

spectacularly, with a tenfold increase in the last few years. A striking example of the growth of an air-cargo carrier is that of the efficient Riddle Air Lines in Miami—now carrying some 25,000,000 ton-miles a year, whereas 10 years ago it started from scratch. Slick, Flying Tiger, and Emery are all equally growing. Although different commodities and different distances naturally result in different tariffs, the general cost of movement of cargo by air is something around 16 cents a ton-mile. Costing over three times that of moving the same goods by motor transport, it looks like a large handicap to overcome.

And here again we run into one of the fallacies that enter into the thinking on air cargo. It is really a mistaken policy to look merely at the cost per ton-mile. What the intelligent shipper should study, of course, is the cost involved in moving the product from the factory floor to the consumer's door. Because of the speed with which cargo can be moved by air, many additional economies enter that can more than outweigh the difference in tariffs that now exist. If these differences in cost were sufficiently understood by shippers, air-cargo movement even today would be on a vastly increased scale:

(1) Insurance against theft and injury while in transit is greatly reduced because the transit time is less than a tenth of what it is by trucking.

(2) Packing costs are greatly reduced because in air transit there is no constant vibrating and jouncing such as on railroads and trucks. The air ride is relatively smooth and very short. And incidentally, a slight additional charge in trucking that requires refrigeration is eliminated in the quick air operations.

(3) Inventories at distribution points of either factory branches or dealers are greatly reduced because the stock on hand need be for only a few days' supply instead of for 1 or 2 weeks.

(4) Warehouse requirements are equally reduced because there is less need for many scattered warehouses to house large inventories in various parts of the country.

Many studies have been made of these various items, and there is no need to burden ourselves with this at the moment, except that we can positively state that these economies are enormous in almost all lines of merchandise and can even become very great economies in the case of automobile dealers. Shipments of new cars from Detroit to Florida, for example, take about 4 days, whereas by air they would only take 4 hours. In these days of multicolored automobiles with such a variety of customer tastes and demands, dealers are quite frantic and losing a great deal of money in large inventories by keeping on hand a supply of cars of the various colors that might entice the customer. Quicker delivery would ensure many a sale of the color wanted.

It follows, therefore, that a discrepancy between 5 and 16 cents a ton-mile can be made up by the above class of economies.

But there are many other ways of reducing the existing costs of air-cargo operations.

The first way, of course, is to design a freight plane. There is no such animal at present. We have, today, only passenger planes with the seats taken out (DC-4, C-46, DC-6, etc.) and military planes designed specifically for the carriage of military loads and for their release by parachutes (such as the C-119 and the C-130). The real 10-ton truck of the air, designed to fulfill commercial operation specifically and so to compete with the 10-ton trailer truck of the road, has yet to be designed. The requirements that a cargo plane would call for involve new design features such as the much more convenient Pallet configuration. Way off in New Zealand, where cargo operations are taken so seriously, the Cargon method of loading a plane has been devised to reduce greatly the expense in time of loading. Another item in design is to incorporate suitable doors in several places. The height of floor has to be adjusted to the height of truck or platform. The possible use of Pods, preloaded, has received only cursory attention.

Literally millions of air drops of small unit deliveries have been made by the military by parachute from cargo planes. There is no reason why this should not be done commercially as the cargo plane flies over the factory to which delivery is to be made.

The use of gliders and glider trains in which a locomotive plane picks up loaded gliders (the equivalent of a freight car) from a factory roof and releases it at destination but continues on its way with its remaining loads has by no means been adequately studied. The late Richard du Pont, the pioneer of "air pickup," had this in mind in his work, and nothing since has proved that such a scheme would be impracticable.

And above all, to reduce further the final cost of shipment by air, we must have not only higher speed while in transit in the air but less time and expense in transferring from landing to receiving platform by designing into our cargo planes such steep landing and take-off characteristics (preferably vertical ones like the helicopter) that a customer's own air landing facilities can be established at his warehouse, his factory, or his distributing point. Only in this way will cargo traffic become independent of the long-runway, passenger jet air-line airports that are now a headache and will continue to be for some time to come.

These economies and steps in progress that will reduce the discrepancy in cost between air cargo and motor transport may well bring the cost down to around 6 cents a ton-mile, at which point it is estimated by traffic experts that the air-cargo traffic that we now know can increase fiftyfold over today's volume.

¡Let us take a look at what we might expect in an air truck to rival the familiar trailer truck of the road. To begin with, we will carry the same load—let us say an average of 20,000 lbs.

This will require a 60,000-lb. aircraft for a range of about 1,500 miles. With two turboprop engines of about 5,000 hp. each (3,000 hp. cruising) and with the most modern streamlining, area rule, and design, a cruising speed of about 350 m.p.h. could be obtained.

If such a plane were run 3,000 hours a year and carried a 10-ton load, it would deliver over 10,000,000 ton-miles a year. In other words, it would be the equivalent of ten Hi-Cube trailer trucks.

Since the trailer trucks would cost about $30,000 each, the first comparative point that poses itself is, can such a plane be built for $300,000? The answer, of course, is that it could be built for less than this—if in the enormous quantity which such a product would go to—particularly as it is so much simpler than either the military or passenger versions of existing aircraft.

Since the first cost is not too great a discrepancy, let us examine some operation items. The truck will run about $3^1/_3$ miles to the gallon, and, on a basis of 100,000 miles-a-year usage (330,000 gal.), the year's fuel cost will be about $66,000 for a fleet of ten trucks.

The single plane that is to replace them at 3,000 hours of flying a year will use about 1,500,000 gal. of fuel which will cost around $300,000. There is, therefore, a difference of over $200,000 in fuel cost. The crew cost of the aircraft is a great saving. Each trailer truck will need about four men at a salary of $5,000 a year, which on ten trailers would give us a salary item per year of $200,000. The air-cargo truck, however, requires two pilots and copilots (the simplest possible operation) at $10,000-a-year salaries which give a total expense per year of $40,000 per airplane so that over half of the extra fuel cost is already recovered in savings of wages. It is not stretching it too far to estimate that the remaining fuel cost difference will be so completely balanced by savings in other things such as those above that we will end up with a cost for shipment by air that may even be less than the shipment by truck, and we get the enormously added speed in the bargain! However, there is one great existing development in air-cargo deliveries that must again be emphasized—to design into these aircraft the ability to land and take off in such small spaces that the use of public airports will not be necessary and air deliveries will be made possible to the door of the consignee.

When we project ourselves into this future era we find that an airplane of this type would carry so much load that all of the trailer-truck cargo moved in the United States could be carried by 27,000 such planes. Obviously, this figure would not be reached for a goodly number of years yet, but it does look today as if a plane that would fulfill these "air-cargo truck" requirements would command a market of 5 to 6,000 in short order. This is a much more important piece of business than any military orders, and yet it will give the military a powerful reserve sinew for war.

In other words here is our problem.

If we can build a 20,000-lb. pay-load cargo airplane, with a 350 m.p.h. cruising speed and a 35 m.p.h. or less landing speed, in quantity, for about $300,000, we can put motor transport out of business at its own price.

This is a big order, but we are near enough there now to begin to sharpen our pencils and our courage and get to work.

▲ ▲ ▲

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Application of Dynamic Programing to the Airplane Minimum Time-to-Climb Problem

It is concluded that dynamic programing offers a method of solution for the climb problem which is fast, is readily adaptable to routine engineering calculation, and allows the inclusion of the effects of variations in airplane weight and drag along the flight path.

Symbols

a, b = matrix designation
C_{D_0} = zero-lift drag coefficient
D = airplane drag, lbs.
g = acceleration due to gravity, ft./sec.^{2}
H = altitude, ft.
i, j = matrix elements
K = drag-due-to-lift factor
M = flight Mach Number
m = number of columns in matrix
N = maneuver load factor
n = number of rows in matrix
q = dynamic pressure, lbs./ft.^{2}
S = reference wing area, ft.^{2}
T = available thrust, lbs.
t = time, sec.
V = airplane velocity, ft./sec.
V_S = speed of sound, ft./sec.
W = airplane gross weight, lbs.
X = horizontal distance, nautical miles
δ = ambient pressure ratio
θ = climb angle, deg.

Introduction to Dynamic Programing

Dynamic programing, as developed by R. Bellman at The RAND Corporation, is a method for solving problems arising from multistage decision processes. In particular, problems in the calculus of variations can be considered to arise from multistage decision processes of a continuous type. In this method, neither constraints nor discontinuities in the expressions involved present any special difficulties. The mathematical theory of dynamic programing has been treated in references 1 and 2 and will not be discussed here. To explain the method we resort to a simple example. Consider the matrix (a):

8	3	4	4
9	4	7	3
1	6	5	2
2	5	1	6

Suppose we wish to travel from position a_{41} to position a_{14} so that the sum of the integers encountered along the way is a minimum. Let us restrict ourselves to moving one integer at a time, either one row up or one column to the right. The obvious technique for finding the minimum-sum or optimal path is to start at a_{41} and try all possible paths through the matrix to a_{14}, finding the solution by inspection. This method of solution, the brute-force or enumerative approach, is usually prohibitive timewise since the number of separate calculations involved is

$$[(n + m - 2)(n + m - 2)!]/[(n - 1)!(m - 1)!] \quad (1)$$

where n is the number of rows and m the number of columns. A 10 by 10 matrix ($n = m = 10$) requires 875,160 separate calculations to try all paths according to our rule for possible moves.

In the theory of dynamic programing it has been shown that by starting at the final position a_{14} and moving through the matrix backward, using the rules given below, we in effect test every possible path without actually performing each numerical operation. The number of calculations now required is

$$2(n - 1)(m - 1) + (n + m - 2) \quad (2)$$

which for a 10 by 10 matrix becomes 180 separate calculations. The advantage of the dynamic programing technique is that it reduces the number of calculations to be performed to a small fraction of those required by the brute-force method.

To illustrate the method of moving through the matrix backward, we return to matrix (a), and construct a new matrix (b) by the rule

$$b_{ij} = a_{ij} + min(b_{i,\,j+1},\, b_{i-1,\,j}) \quad (3)$$

where the symbol $min\ (x, y)$ means the smaller of the two quantities. At the upper row

$$b_{ij} = a_{ij} + b_{i,\,j+1} \quad (4)$$

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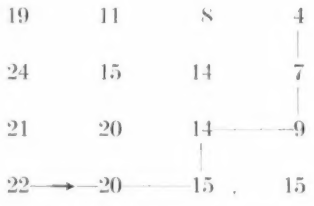
and at the right-hand column

$$b_{ij} = a_{ij} + b_{i-1,\,j} \tag{5}$$

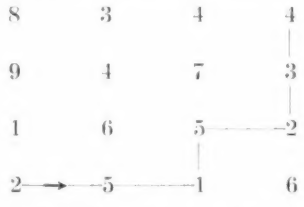
Using Eqs. (3)–(5) we obtain matrix (*b*):

19	11	8	4
24	15	14	7
21	20	14	9
22	20	15	15

Matrix (*b*) has the property that an element b_{ij} is the sum of elements of a_{ij} encountered along the optimal path from a_{ij} to the final position a_{14}. Consequently, when we start at position b_{41} in matrix (*b*) and move successively according to our restrictions to the smaller of the two possible integers, we are following the path of minimum-sum in matrix (*a*). By inspection, the path we should follow through matrix (*b*) is



This path through matrix (*b*) corresponds to the path through matrix (*a*), shown below, which is the desired solution to our example problem:



It will be noted that the sum of integers along the optimal path from a_{41} to a_{14} is 22, which corresponds to the element b_{41} in matrix (*b*). Consequently, matrix (*b*) gives us not only the indication of the optimal path through matrix (*a*) but also the sum of the integers along this path.

Application to Climb Problem

Turning to consideration of airplane performance, time-to-climb is given by the expression

$$t = \int_{H_1}^{H_2} [1/(dH/dt)]dH \tag{6}$$

where

$$\frac{dH}{dt} = \frac{(V/W)(T - D)}{1 + (V/g)(dV/dH)} = V \sin\theta \tag{7}$$

Time-to-climb can therefore be expressed functionally as

$$t = f[H,\ V,\ \text{throttle setting},\ \theta,\ (dV/dH),\ (d\theta/dH)] \tag{8}$$

Since climb is usually at a fixed throttle setting, especially for the minimum-time case, we can write

$$t = f[H,\ V,\ \theta,\ (dV/dH),\ (d\theta/dH)] \tag{9}$$

The problem of finding the minimum-time path from one point to another in the altitude-velocity plane is to minimize Eq. (9). Problems of this type are subject to solution by the calculus of variations, and this approach has been tried by Kirkwood,[3] Miele,[4] and others. Solution by the calculus of variations, however, presents difficulties, among which are complexities of formulation and, in some cases, indeterminate solutions. For engineering use this approach may be intractable. Another approach, the energy method, is presented by Rutowski.[5] This approach, while seemingly better suited to engineering use than the calculus of variations, is objectionable because only the initial and final altitudes, and not the associated velocities, can be specified. Further, the unrealistic assumption is made that dives and zooms are accomplished in zero time. By formulation and solution of a typical example case it will be shown how the application of dynamic programing eliminates the mentioned objections to both the calculus of variations and energy approaches and introduces several advantages as well.

Analogous to our original example, we now consider the a_{ij} matrix to be an a_{HV} matrix, where each row represents an altitude and each column a velocity. Let the top row be the desired final altitude, the bottom row the starting altitude, the left-hand column the initial velocity, and the right-hand column the final or limiting velocity. What we require is a path of minimum time from a_{H_I, V_I} to a_{H_F, V_F} where H_I is the initial altitude, V_I the initial velocity, and H_F and V_F the final altitude and velocity, respectively. The elements a_{HV} are now taken to be the time required to climb from one row to the next at constant velocity or to accelerate from one column to the next at constant altitude. When ΔH, the altitude change between adjacent rows, and ΔV, the velocity increment between adjacent columns, are sufficiently small, any path can be arbitrarily closely approximated by combinations of incremental climbs and incremental accelerations. We have chosen to limit the airplane to these two moves although this is not a necessary restriction upon the method.

We now define the (*b*) matrix as follows:

$$b_{HV} = min \begin{bmatrix} a_{H+\Delta H,\ V} + b_{H+\Delta H,\ V} \\ \text{or} \\ a_{H,\ V+\Delta V} + b_{H,\ V+\Delta V} \end{bmatrix} \tag{10}$$

This matrix is formed, as in the example, by starting in the upper right-hand position, the end point, and moving backward through the matrix so that $b_{H+\Delta H,\ V}$ and $b_{H,\ V+\Delta V}$ are known before b_{HV} is calculated. In other words, the minimum time to climb from any point (H, V) to the end point is the minimum of two possibilities: the time to climb ΔH plus the time to fly from ($H + \Delta H$, V) to the end point, or the time to accelerate ΔV plus the time to fly from ($V + \Delta V$, H)

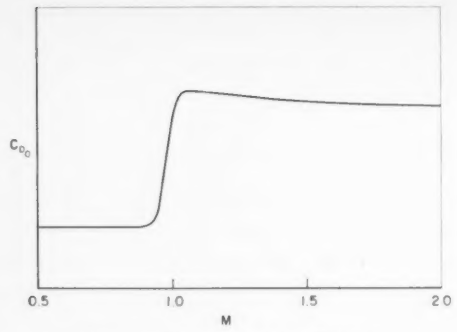


FIG. 1. Zero-lift drag coefficient.

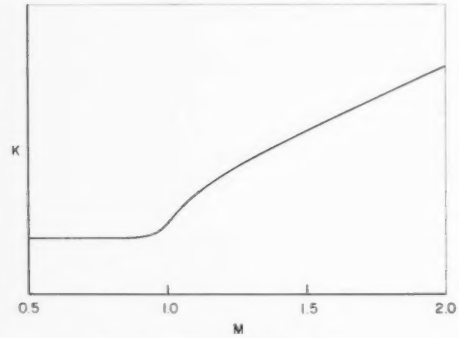


FIG. 2. Drag-due-to-lift factor.

to the end point. Once matrix (b) is completed, it is necessary only to proceed through it, starting at the initial point, and to select the smaller of the two possible adjacent elements to establish the optimal path. Again, as in the example, each element b_{HV} represents the minimum time to fly from that element to the end point.

As a consequence of the formulation of matrix (b) [a process requiring only the number of separate calculations indicated by Eq. (2)], the optimal path from any point (H, V) to the end point and the time required along this path have been established. The treatment of the effects of airplane weight-change along the path and the effects of the climb path on airplane drag are presented in the next section.

EXAMPLE PROBLEM

To show numerical results of the application of dynamic programing to the minimum time-to-climb problem, a hypothetical interceptor airplane was selected capable of flight at a speed equivalent to 2.0 Mach Number and an altitude of 60,000 ft. Drag for this airplane can be represented by

$$D = C_{D_0} qS + (KN^2W^2/qS) \tag{11}$$

where

$$q = 1{,}481\ \delta M^2 \tag{12}$$

$$N = \cos\theta + (V^2/g)(d\theta/dH)\sin\theta \tag{13}$$

C_{D_0} and K, the zero-lift drag coefficient and the drag-due-to-lift factor, respectively, are functions of Mach Number, as shown in Figs. 1 and 2. The available thrust is a function of altitude and speed if throttle setting is fixed (Fig. 3). The equivalence between Mach Number and velocity is given by

$$M = V/V_S \tag{14}$$

where V_S is a function of altitude only.

We proceed by forming matrix a_{HM} for which we have chosen $\Delta H = 1{,}000$ ft. and $\Delta M = 0.02$. A starting point of ($H = 0$ ft., $M = 0.8$) and a final point of ($H = 60{,}000$ ft., $M = 2.0$) result in a 61 by 61 element matrix. (The matrix need not necessarily be square.) The time to climb ΔH at constant Mach Number is given by

$$\Delta t = \frac{\Delta H[1 + (V/g)(\Delta V/\Delta H)]}{(V/W)(T - D)} \tag{15}$$

and the time to accelerate ΔM at constant altitude is given by

$$\Delta t = (W/g)\Delta V/(T - D) \tag{16}$$

For small Δt the horizontal distance covered in both climbs and accelerations is computed as the product of Δt and the average horizontal velocity component.

Using Eqs. (11)–(16), matrix b_{HM} was developed by a high-speed digital computer, and minimum-time paths were determined for several cases. The results are shown in Figs. 4–6. In Case A, the gross weight of the airplane W was held constant at 40,000 lbs. and the load factor N was assumed equal to 1.0. The time-to-climb along the optimal path for Case A is 277 sec. Fig. 4 shows the altitude - Mach Number trace of this path, while Fig. 5 shows the altitude - horizontal distance profile.

In Case B, the effect of changing gross weight along the flight path was examined by introducing the specific fuel consumption as a function of altitude and speed. Since we must move backward through the matrix b_{HM}, the technique employed is an iterative process, starting with several assumed values of final gross weight and calculating the increase in gross weight as we move backward through the matrix. The interesting by-product of this technique is that we have available time-to-climb data for a variety of starting gross weights, as shown in Fig. 6. For a

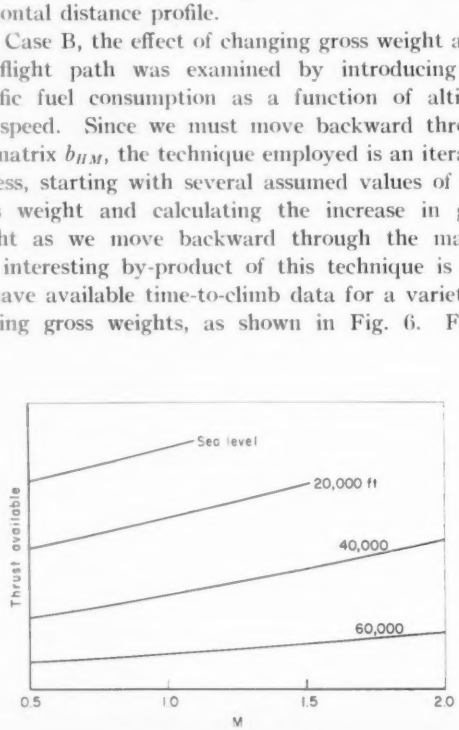


FIG. 3. Thrust available.

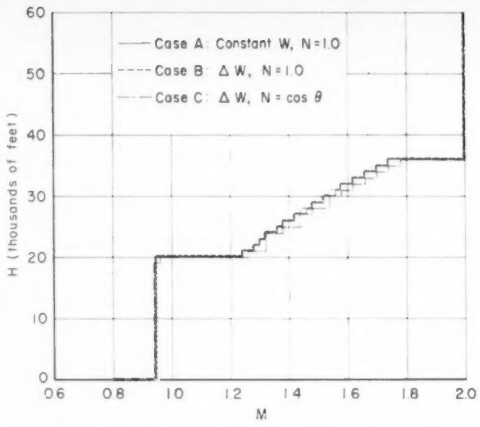


FIG. 4. Altitude - Mach Number trace of minimum-time paths.

starting gross weight of 40,000 lbs. and a load factor of 1.0, time along the optimal path is 252 sec. and the fuel is 3,452 lbs. The altitude - Mach Number trace and flight profile for Case B are shown in Figs. 4 and 5 for comparison with Case A.

For Case C, the effect of including the climb angle in the airplane drag ($N = \cos\theta$) was investigated. The effect on drag of normal accelerations, the right-hand term in Eq. (13), was ignored. The technique for including $\cos\theta$ in the drag is an iterative process similar to that used for a gross-weight change. As in Case B, a weight change was considered for Case C. The results are shown in Figs. 4 and 5. The time-to-climb for Case C for a starting gross weight of 40,000 lbs. and $N = \cos\theta$ is 251 sec. Further refinement to include the effect of normal accelerations on drag could be introduced by adding another dimension to the matrix formulation, but this was not done in the present study. The effect of the normal accelerations on the flight path may be significant, especially in the regions of transition such as the leveling-off from climb to level acceleration.

The results show that, for the example problem, the altitude-velocity trace and the altitude-distance profile of the optimal path are fairly insensitive to gross-weight changes and drag corrections and that the minimum time is insensitive to drag corrections due to flight-path inclination. The time-to-climb is, however, seen to be quite sensitive to gross-weight changes.

Turning now to practical application of these results, it is clear that no pilot would be expected to follow complicated altitude-velocity climb schedules such as those in Fig. 4. Fortunately, it can be shown quite readily that any of the paths in Fig. 4, for example, can be closely approximated timewise by a path which employs two constant-Mach-Number climbs and a constant-altitude acceleration only. Thus, the most useful purpose of the theoretical solution may well be to establish practical minimum time-to-climb paths.

CONCLUSIONS

The following conclusions can be drawn from this study of the application of dynamic programing to the airplane minimum time-to-climb problem:

(1) Dynamic programing offers a method of solution to the climb problem which is fast, is readily adaptable to routine engineering calculation, and allows the inclusion of the effects of weight changes and drag corrections along the flight path.

(2) Practical climb schedules for minimum time from any starting point in the flight spectrum can be established by a single application of the dynamic-programing method.

Dynamic programing can also be employed to determine paths of least fuel consumption and may be applicable to the general missile-guidance problem.

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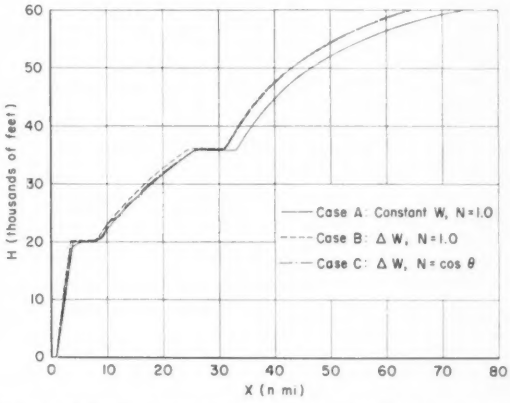

FIG. 5. Altitude - horizontal distance profile of minimum-time paths.

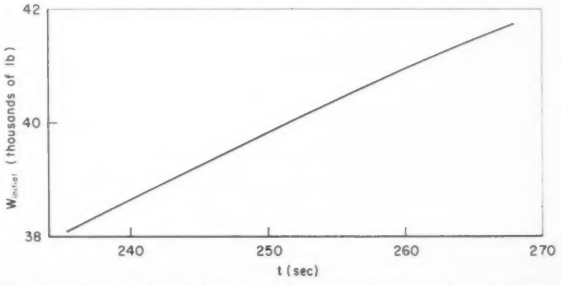

FIG. 6. Effect of initial gross weight on minimum time to climb.

"The iterative method described permits a defense complex to be designed from the outer reaches of the defense position inward to the vital areas."

Criteria for the Design and Selection of a Defense Complex

L. L. Stahl*
General Electric Company

Introduction

It is the purpose of this paper to conduct a macroscopic examination of a defense complex which performs a stated defense function—e.g., all of the antiaircraft guns, surface-to-air guided missiles, and fighter interceptors comprise the defense complex against today's enemy bomber. It discusses in considerable detail a methodology which permits development of design criteria and also touches on selection principles. In addition, it uncovers what the author believes to be a new approach to the problem of determination of weapon system design requirements and further indicates their employment in terms of geography and quantities.

During the early stages of the inception of the design of a defense complex, this design was identified by the author as "system-squared." It is obvious how this name originated, and the author feels it to be a most descriptive term. Defense complex design is a problem in determining an appropriate system of contributing weapons systems. The input to the complex is, of course, the total threat, and the output of the complex is an acceptable level of defense. This immediately says that the threat is brought to bear first against the peripheral weapon systems; and after this engagement, some particular portion of the threat remains. This remainder is then engaged by weapon systems placed nearer the vital areas, and each in turn has as its output a threat residue. Obviously, the location and the quantities of systems must be treated together with their characteristics. Even a simple "system-squared" possesses so many variables that a closed-form statement appears impossible. For this reason, the method described later was used. It is an iterative process which permits the development of sufficient information that permits the designer to gain an understanding of the interrelationship of weapon systems and their contributions to the overall complex.

* Missile and Ordnance Systems Department.

Concepts of Defense

As one looks around at various weapon systems that have defense as their primary mission, it soon begins to be apparent that the systems came into being in a rather unilateral fashion. It is unilateral in that its relationship to existing and planned systems was given little or no sober consideration. More specifically, as technology progresses and a weapon that is somewhat better than existing weapons appears to be feasible, pressures mount and another system is added to the military inventory. As one would believe, and as history has evidenced, this causes duplication and overlapping and sometimes leads to disagreements on military responsibilities for defense.

In the postwar years, there has been a lot of attention given to the problem of weapon system design. Many competent people have scrutinized the weapon system problem, and I feel it is safe to say that it is now fairly well understood. All, or at least most, of the weapon system thinkers begin with the postulation of a requirement for the weapon system. They must necessarily do this, else they have no beginning point. In view of our increased understanding of operations research and engineering techniques, a pertinent problem is the determination of appropriate contributing systems. The scope of this paper is further narrowed down to a defensive complex because the author has been considering this problem for some time and feels that at least the reference frame of the problem is now understood.

To begin the design of a defense complex, we should first look at defense from the military viewpoint. Generally, there are two ways to defend. The first is to put a ring of defensive systems around the vital areas and wait for the attack to come. In air defense terminology, this is known as local or point defense. Historically, antiaircraft artillery has provided local defense. Another course of action is to employ another long-range, intelligence-gathering system and then proceed to the attacker as soon as his presence is known.

Reaching out in this fashion obviously develops the enemy attack and begins to effect an early attrition. It further permits the defender to change his *modus operandi* in the presence of attack. This tactic in air defense has been called area defense. The one feature which distinguishes it is its tactical mobility. The classic area air defense weapon is the interceptor aircraft.

Obviously, local defense has good points and bad points. Because of operation at reduced distances, the system is easier to conceive, design, develop, and manufacture. Further, the hardware cost for such a system is less than the cost for longer-range systems. On the other hand, the systems must always be in a position to react after the attack is developed. This means that they are faced with more difficult saturation problems and increased susceptibility to countermeasure efforts. Unique to air defense is the pressing problem posed in the location of local defense weapon systems. In highly industrialized and populated areas, real estate is at a premium, and it is this same real estate that the local defense systems require for their employment.

Area defense has its advantages and disadvantages. The only realistic disadvantage is a technical one. Here the requirement for detection at greater distances and for a vehicle moving swiftly to a distant point of intercept and effecting a kill taxes technology and state of the art to the utmost. At times it is taxed to such an extreme that that which is obviously logical cannot be supported from a hardware viewpoint. It does, however, give us the ability to reach out early in the battle and begin the attrition process. As it becomes apparent that more and more defense must be brought to bear, the mobility of the vehicles in the systems permits them to be concentrated to provide an acceptable defense. By virtue of this process, it is much more difficult to saturate area systems than local systems. Safety afforded the vital areas is much higher with an area-type defense because the engagements take place at considerable distances from the vital areas. Another extremely important factor is the increasing lack of sensitivity to geographic location of defensive systems with greater and greater defense ranges. Thus, the problem of selecting and obtaining the necessary real estate is greatly facilitated.

By now one begins to say, "All I need is area defense." This is not true, and I believe a simple case illustrates the need for balance between systems. Large-caliber artillery pieces are for employment at great ranges to destroy enemy forces. However, if some guerilla has infiltrated the artillery position and suddenly runs out of the woods in the vicinity of the large-caliber weapon, it cannot be brought to bear on this man. We need that ever-dependable pistol to kill this soldier who has gotten in past the minimum range. Even if we could use the large-caliber artillery piece, it would be extremely uneconomical to kill him with such a device. This is admittedly an extreme example, but it is used to lead into the need for defense in depth. If a defender is to be successful, he must, at the earliest time, begin his defense and obtain the highest possible attrition rate as the enemy continues toward the vital area being so desperately protected. There is no one "cure-all" system. There is no one system which is economically optimum under all extremes. Lastly, a purely military consideration precludes one system because then the enemy would have only to overcome—countermeasure—that system, and he would have nullified the defense.

Thus far we have discussed two concepts of defense—local and area—and have in no way described the appropriate number of contributing weapon systems.

Realistic appraisal of scientific and technical phenomena points to different systems for defense. When transit times are short between launch and intercept, little or no intelligence is required in missile or projectile. As transit times increase, the need for more sophisticated intelligence systems goes up. Propulsion considerations and structural considerations clearly show "knees" in design curves where a shift is indicated from one technical solution to another.

In summary, purely military considerations lead to the conclusion that more than one system, perhaps several systems, are needed for an adequate defense. In the same vein, scientific and technical facts of life point to more than one system which can do the job effectively. It is at this point that one clearly sees a group of systems emerging as the requirement, and this is what we choose to call the complex of systems—the defense complex. There is a further connotation here in complex and that is the correct proportions of effective weapon systems.

The Design Process

The first logical step in the complex design is obviously a determination and precise statement of the threat. The threat must be described in terms of that facing the complex of weapon systems. Needless to say, intelligence estimates must be analyzed together with probable enemy tactics to arrive at the technical description of the target vehicle, and included with this must be the tactics being used and the quantity of enemy vehicles. This is one of the most critical facets of the analysis; however, there is a lot of information that can be brought to bear by both the military planner and the engineer as they search for a reasonable postulation of the threat. At the risk of repetition, the threat is that seen by the complex. This will consist of the target array as it first encounters the entire defense perimeter and later of the array just approaching this limit plus the then existing residues which have successfully penetrated certain systems.

Next are needed technical feasibility studies which define the inner and outer limits of weapons capable of producing kills. This look at technical feasibility must keep a sharp focus on only those problem variables which are questionable from a state of the art or reasoned-forecast viewpoint. They do not answer any detailed questions but generally indicate the plausibility of a system of certain defense volume and kill potential.

To be more specific, in an air defense analysis these studies would indicate maximum and minimum detection, location, kill ranges, and altitudes. The minimum values are of course dictated by the bomb-release line or lethal radius of mass destruction warheads. Thus is established the spectrum of feasibility, and the boundaries of the battle emerge in rough form for the first time.

Having established the feasibility spectrum, it is now necessary to identify arbitrarily systems to be factored into a more detailed war-game process. At first glance, one need make a completely arbitrary decision, and there can be an infinite number of choices. This is not so. Military considerations give guidance in terms of local and area concepts. Technical considerations will serve to limit the selection if on no other basis than time available to permit interceptions. Obviously, there comes a last course possibility which is identified with the historic bomb-release line. One can envisage political implications having an impact on the selection, but this is not clear in the general case.

Next comes the real chore. Keep in mind that we have agreed upon the threat. The defense complex is comprised of some combination of the systems we have selected. "What systems?" is the most challenging question. The most logical step at this time is to begin an end-game process by letting the threat come in toward the various weapon systems chosen and to proceed in employing sufficient quantities of selected systems to achieve a required defense posture. Clearly, any one system in some quantity will do the job. Mixing the systems in various proportions can also produce the required defense. In view of work conducted, it appears that one continues to change types, locations, and quantities of systems until trends are established and a reasonable amount of understanding emerges from the analysis of all variables considered. This procedure is felt to be valid because there are too many variables to permit a reasonable identification of a closed-form statement of the problem. It is interesting to note that several examples calculated by the author have shown that simultaneous use of different range systems produces an acceptable defense for an appreciable percentage saving.

The Selection Procedures

Now, for the first time we are in a position to ask ourselves what message is contained in the results of our investigative efforts. It has not been so stated, but we have been considering only active defense. It is now proper to look at the economics of active versus passive defense. The economic justification follows completely from the cost of achieving a certain defensive posture by passive means as opposed to achieving the same level of defense posture by active means. The economic justification criterion says: Do we use active defense or passive defense?

One of the best and most comprehensive measuring devices to compare defense complexes is contained in a cost-effectiveness quotient. This is defined as the dollar cost to destroy a single, attacking target. This cost is determined by permitting an arbitrary threat to be engaged by the complex and then dividing the number of targets destroyed into the total cost. This cost includes purchase of equipment, purchase of ammunition, purchase or lease of real estate, logistic support, salaries of personnel, training cost, and amortization of equipment. If one of the complexes evaluated is a standout performer on a cost/effectiveness basis, the selection is made quite easily. In the general case, there will not be an appreciable spread between two or three or four complexes which are obvious choices. Cost/-effectiveness considerations will enable us to throw away the marginal systems and leave a group which, on that basis alone, is equally good. So far, we have applied to the selection no other design criteria and may well have no good course of action clearly identified.

There must then be other common denominators of comparison to assist in the design and selection of the complex. Personnel is one of the first to pique our curiosity at this stage in the design. Here we must ask what quantity of people (and with what levels of skill) is needed to operate these systems which are still running "neck-and-neck." It may well be that we still have systems with large numbers of reasonably well-trained individuals, as well as systems not requiring highly skilled specialists. A good comparison yardstick for personnel seems to be the detriment incurred in the gross national product by the selection of one or the other defense complexes. Specifically, the contribution to the gross national product of the personnel required for the competing complexes needs to be determined. Clearly, that which is the least drain gets a favorable nod.

Countermeasures which degrade the effectiveness of systems are difficult to assess. One of the greatest difficulties arises in that the success or failure of countermeasure efforts revolves, to a greater degree than any other, around the individual skill of the equipment operators. Nevertheless, certain systems by their very nature are less vulnerable than others. It must be assumed that the enemy will solve the riddle of the systems in the complex sooner or later. The ability of the system to operate in the face of an intelligent enemy must be assessed, and, further, the potential for decreasing susceptibility must be examined. The initial burden placed on the enemy and our capacity to provide counter-countermeasures provides a qualitative and quantitative measurement.

Having more than one system in a complex poses a difficult systems management and control problem. Historically, these interfaces between systems cause confusion and compound the complexity of control. There is a difficulty that is encountered when one attempts to pass detection, location, identification, and threat potential information from one system of destruction to another. The fewer the interfaces, the simpler the complex and the better its chance of success.

The growth potential of a complex is indeed a serious matter. Probably more lip service has been paid to the term "growth potential" than to any other. Growth potential must be examined from at least two distinct aspects. The obverse side of the coin is that which examines the ability of the system to live efficiently in an enemy environment which is reasonably forecast. The reverse side of this growth coin looks at the ability to produce a better system without destroying all of the capital investment plus the investment in trained personnel. Growth in this sense is not that of discarding a system for one with the same name and longer range. Rather, it should be thought of as obtaining significant improvement in the complexes' capabilities and yet retaining a major portion of the original capital investment. Two measurements can be seen in this growth potential. First, what does it mean in terms of men and money to defend acceptably against the next enemy attack potential? Second, what costs do we incur to provide the next logical upgrading of the currently planned complex?

One additional design criterion can be brought to light by looking into the investment cost and the operating cost. The useful military life of equipment is readily forecast. Its total cost consists of the price to buy plus the price for maintenance and the price for operation. Systems with low first cost could well be prohibited from an operating and maintenance viewpoint. On the other hand, putting a lot of money into a first cost is risky—risky because an error in the estimate of its useful life could result in being forced to retain the system because of lack of dollars. We can develop a selection criterion here by ascertaining how readily present and future costs mesh with anticipated military budgets.

Clearly the selection criteria are not in any fashion mutually exclusive. In the general case there are several complexes remaining as we approach the selection stage of our problem. These complexes are not of themselves rigidly defined—rather they represent a scheme. As we successively examine the complexes against the selection criteria we soon see where slight alterations should be made in the scheme of the complex to improve its military attractiveness. In all probability a complex which rates high against one criterion may not fare very well against others. Thus we come to the end of the selection process and find that we are able to rank our various remaining complexes in each of the criteria. These data are then weighed in the balance to arrive at that complex, or scheme, which we feel to be the best.

Conclusion

There are some further fruits to our labors. It should be shown that a certain one of the systems in the complex offers a greater contribution to the net effect. Other things being equal, this is the system whose development should be initiated first. It is further reasonable to identify common problem areas in the indicated systems. In this age of limited military budgets, such an identification can result in an all-out effort to establish techniques which contribute to the success of more than one system and so produce considerable dollar saving.

As we study and analyze a complex, our knowledge and understanding of the contribution of the various weapon systems may possibly indicate the desirability of changes in weapon system characteristics. We recall that the systems introduced into the analysis were optimum as individual entities, and an alteration of certain system characteristics may well have a pronounced beneficial effect on the complex. Let us define redesignation as an alteration of weapon system characteristics—from those which either military or technical considerations show to be an optimum—for the purpose of improving the complex. Work which has been done in this problem area has not established what we choose to call redesignation, but it is felt that it can be established. Another way of saying this is that the further understanding of the complex can well show that appreciable changes should be made in the initial selection that was based on the technical and military aspects.

In summary, the iterative method described permits a defense complex to be designed from the outer reaches of the defense position inward to the vital areas. It completely rejects the philosophy of agreeing on a happy solution and then continually expanding outward. It is more logical when one considers that the battle develops from the peripheral areas toward the heartlands or the vital areas. Clearly, as our weapons of great defensive range begin to attrite the threat, the lesser range systems find themselves in a different environment but in the realistic environment in that it is the one now remaining. This process continues as the battle progresses, and the systems are placed both quantitatively and by type to provide the optimum cost effectiveness in the successive areas of interest. We have thus, by a combination of operations research and reasoned system analysis, identified the requirements for the contributing weapon system of the defensive complex.

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NEWS OF MEMBERS

(*IAS News continued from page 39*)

▶ **Air Commodore F. R. Banks** (HF), a Director of the Bristol Aeroplane Company Limited, Filton, England, will be Chairman of the firm's new American subsidiary, The Bristol Aeroplane Company, Inc., New York.

▶ **Lt. Gen. Laurence Craigie,** USAF (Ret.) (AF), who recently retired as Vice-President, Engineering, Hydro-Aire, Inc., has joined American Machine & Foundry Company as Assistant to the AMF Defense Products Group Executive, in charge of long-range planning. General Craigie also is an IAS Vice-President.

Members on the move . . . .

This section provides information concerning the latest affiliations of IAS members. All members are urged to notify the News Editor of changes as soon as they occur.

Clare E. Barkalow (M), formerly Vice-President and Engineering Manager of Gyromechanisms Division, Norden-Ketay Corporation, has joined Lear, Inc., as Associate Manager, Advanced Engineering Division.

Eric J. Catchpole (M), formerly Personal Assistant to the Managing Director, Aero Research Limited, has been appointed Manager of the firm's Bonded Structures Division.

Milton Evans Chandler (AF), cofounder of Chandler-Evans Company, has retired from active duty as Engineering Manager. He will continue to be available on a consultative basis for the firm, now a division of Pratt & Whitney Company, Inc.

Rear Adm. Delmer S. Fahrney, USN (Ret.) (AF), has been appointed Secretary to the Committee on Science and the Arts of The Franklin Institute. Admiral Fahrney also is Historian, Radio-Controlled Aircraft & Guided Missiles, BuAer.

Hans R. Friedrich (AF) has been promoted to Assistant Chief Engineer, Development, with Convair-Astronautics, A Division of General Dynamics Corporation. Dr. Friedrich formerly was Chief Flight Mechanics Engineer for the same firm. He also has been named a member of the NACA Sub-Committee on Power Plant Controls.

Dale Hamilton (AF), formerly H-21 Project Engineer for Vertol Aircraft Corporation, has joined Ludwig Honold Mfg. Co., sheet metal fabricators, as Chief Engineer.

Ephraim M. Howard (AF) has joined Marquardt Aircraft Company as Assistant to the Executive Engineer, Powerplants Engineering Subdivision. He formerly was a Senior Project Engineer with Allison Division, General Motors Corporation.

Donald E. Rialson (M), formerly Associate Chief Flight Test Engineer for Hughes Aircraft, has been appointed Chrysler Corporation's Air Force Missile Test Center, Manager of Operations.

Dale A. Lichty (A) has been elected President of Hydro-Aire, Inc., to succeed Homer H. Rhoads (A) who has resigned. Mr. Lichty had been Senior Vice-President of the firm.

Necrology

Charles E. Craven

The Institute mourns Charles E. Craven (M), 34, killed March 29 in the crash of an experimental B-52 near Skiatook, Okla.

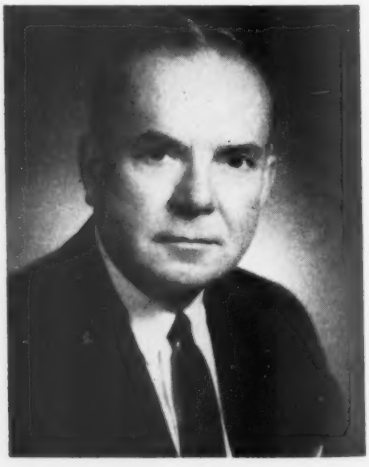
Mr. Craven was an Experimental Test Pilot for the Boeing Airplane Company, Wichita Division. An aeronautical engineer with 11 years' flying service in the Navy, he joined Boeing last August.

He was born in Big Spring, Tex., and attended Texas Western College, El Paso, for 3 years, receiving his degree from the U.S. Navy Postgraduate School in 1949. He obtained a Master's degree in aero-

Jerome C. Hunsaker (HF) has been presented with the NACA's highest award, the Distinguished Service Medal, for "service of fundamental significance to aeronautical science, climaxed by an outstanding and unparalleled record of leadership during the past 15 years. . ." Dr. Hunsaker was NACA Chairman from 1941 until last October.

Edward Warner (HF) has been named first Honorary Member of the International Society of Aviation Writers at the new organization's first general meeting. The honor was given to Dr. Warner "in recognition of a lifetime of inspiring leadership and devoted effort in the cause of internationalism, civil aviation, aeronautical education, and professional aviation writing."

Charles W. Meyers (M) has been appointed Director, Product Planning and Development Division of American Steel & Wire's General Sales Department. American is a division of United States Steel Corporation. Mr. Meyers had been Manager of Manufacturers Products Sales.



Painting by Chesley Bonestell from the book *The Exploration of Mars* by Willy Ley, Wernher Von Braun and Chesley Bonestell, published by Viking Press ($4.95). ©C.B.

Space... Time... and Temperature ...with Fenwal aboard

Space and time accommodate no man. But temperature is a little more obliging.

Space ships probably will have miracle-metal blinds that open automatically on the part of the cabin exposed to sun rays and close on the cold side. Who will make the temperature controls? Fenwal, it is likely.

That's because of the advanced job Fenwal has been doing on modern aircraft and missiles. Not only have the temperature sensing problems themselves been solved practically and reliably — but the factors of continued good service under shock, vibration and extreme climatic conditions are being met also.

A good example is Fenwal's leadership in differential thermostats, controls for camera compartments, cooling effect detectors, bearing over-heat alarms and other specially packaged controls. What we do today is preparing us for tomorrow.

To enlist Fenwal's ability to help meet *your* present and future control problems, write Fenwal Incorporated, Aviation Products Division, Ashland, Massachusetts.

Fenwal *Controls Temperature... Precisely*

FENWAL UNITS WATCH POTENTIAL HOTSPOTS

Quick, Accurate Units Advance Aircraft Safety

ASHLAND, MASS. — Over-heat protection and temperature control in aircraft have been given a big boost by Fenwal engineers here. They've produced a broad line of extremely accurate and reliable temperature detectors and controls for aircraft.

Based on the unique THERMOSWITCH® principle, the units provide unfailing operation and exact repeatability. This principle is differential expansion wherein the activating control element is a single-metal shell. This single metal shell expands or contracts with temperature changes, making or breaking the totally enclosed electrical contact.

Vibration, shock and climate extremes have no adverse effect on the Fenwal units.

The line embodies heater controls, cooling effect detectors, differential thermostats, baggage compartment over-heat detectors and midget and miniature controls for tight-spot installations.

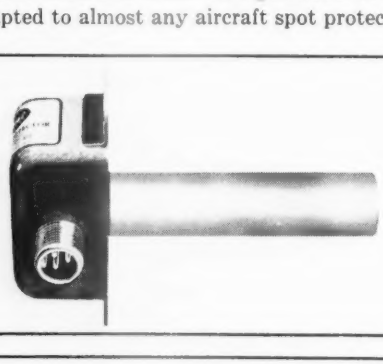
All are extremely light and compact.

For details on any or all, write to **Fenwal Incorporated, Aviation Products Division, 175 Pleasant St., Ashland, Massachusetts.**

Fenwal

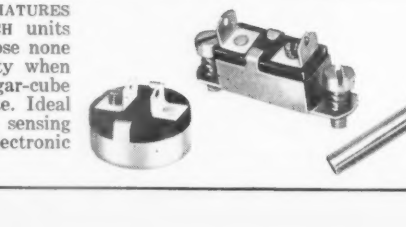
CONTROLS TEMPERATURE ...PRECISELY

Here are just a few examples of how Fenwal has solved the problem of over-heat protection and temperature control — and there are several thousand other configurations of these units that can be adapted to almost any aircraft spot protection problem.



COOLING EFFECT DETECTORS — Functions in same manner as equipment it protects, to sense effect of cooling air.

HEATER CONTROLS, BAGGAGE COMPARTMENT FIRE DETECTORS, DIFFERENTIAL THERMOSTATS — Each uses the THERMOSWITCH unit principle, meaning that each fulfills its special function aboard aircraft with unmatched accuracy and quickness of response. All such units, regardless of function, are light, compact, and hermetically-sealed in stainless steel.



MIDGETS AND MINIATURES — THERMOSWITCH units for tight spots lose none of their reliability when reduced to sugar-cube and cigarette size. Ideal for temperature sensing in compact electronic equipment.

nautical engineering from the University of Michigan in 1950.

Mr. Craven was a fighter pilot in the Pacific during World War II and served for 2 years as a pilot on the U.S.S. "Princeton" during the Korean War. He had logged more than 4,000 hours' flying time.

Prior to joining Boeing, he was an Engineering Test Pilot for Douglas Aircraft Company.

Roland E. Owen

Roland E. Owen (M) died January 31 in the collision of an F-89 Scorpion with an air liner over Pacoima, Calif. He was 35.

Mr. Owen was Assistant Chief, Production Flight Test, Northrop Aircraft, Inc. A native of Los Angeles, he had logged more than 1,000 hours in single- and multi-engined jet aircraft during 4 years of flight testing.

He was graduated from the University of Southern California with a B.S. in business administration in 1951. From 1941 to 1946, Mr. Owen was a Navy carrier-based fighter pilot. He also was a Lieutenant in the Naval Reserve.

J. Henry Reisner

News that a heart attack has killed J. Henry Reisner (M), in Miami, has reached the Institute. He was 51.

A native of Hagerstown, Md., Mr. Reisner was one of the nation's early fliers and a pioneer in construction and design of racing planes. Among his racers were the KR1, which won the Scientific American Trophy in 1926, and the Challenger C2. At the time of his death he was Staff Engineer, Eastern Office, Aeroquip Corporation.

Mr. Reisner was a founder of Kreider Reisner Aircraft Company later bought by Fairchild Aviation Corporation. He was commissioned a Lieutenant in the Naval Reserve in 1933 and served as an Aviation Special Officer from 1937 to 1938.

He was a member of the American Rocket Society, Society of Automotive Engineers, Wings Club, American Ordnance Association, Flight Safety Foundation, and National Aeronautical Association.

George L. Shue

Word of the death on March 21 of George L. Shue (AF) has been received by the Institute. Dr. Shue was 53. He died in San Diego, Calif.

A Design Specialist at General Dynamics Corporation, Convair Division, Dr. Shue began his scientific career at the Colorado School of Mines as a physics instructor in 1927. A native of Denver, he pursued a teaching career before aeronautical engineering. He taught at Montana School of Mines where he was Professor of Physics and Mathematics from 1930 until he joined Consolidated Vultee in 1942. He worked as an aerodynamicist for the forerunner of Convair but after 1 year returned to teaching (applications of heat transfer) at the University of Texas.

Dr. Shue returned to Consolidated Vultee as Aerodynamics Engineer in 1944. He was made Supervisor—Stability, Control, and Aerodynamics Research Group, at the San Diego plant.

Beside the IAS, he also was a member of the American Physical Society and Montana Society of Engineers. He received a Ph.D. in physics from the University of Southern California in 1936 and was a Ground Instructor and Coordinator of Civilian Pilot Training from 1939 to 1942.

Ernest W. Stedman

Word of the death on March 27 of Air Vice-Marshal Ernest W. Stedman, RCAF (Ret.) (F), former Director General of Research, Royal Canadian Air Force, has been received by the Institute. He was 69.

A graduate of the Royal College of Science, London, Marshall Stedman went to Canada in 1920 as Chief, Technical Directorate of the Air Board. Four years later the RCAF was formed and he joined it. He retired in 1946.

Marshal Stedman was Assistant Aeronautics Director, National Physical Laboratory (Great Britain) from 1913 to 1914. He served in the Royal Naval Air Service and RAF from 1914 to 1919 and was Chief Designer, Handley Page Limited, from 1919 to 1920.

He was a Fellow, Royal Aeronautical Society; Honorary Fellow, Canadian Aeronautical Institute; Member, Institute of Civil Engineers; Associate, Royal College of Science; and Member, Engineering Institute of Canada.

CORPORATE MEMBER NEWS

• **Aerojet-General Corporation** has agreed to exchange technical knowledge on liquid fuel rocket engines with D. Napier & Son Limited, England. High test peroxide rocket engines are involved. . . . Engineers have successfully tested the firm's Aero-Brake thrust-reverser on an Allison J-71 engine. The reverser was developed under license from the French firm SNECMA.

• **Aeronca Manufacturing Corporation** announced plans to erect a new plant addition and office building in line with an expansion program approved by the firm's Board of Directors. A Planning Committee has been organized to direct expanding research and development activities. Industrial Research Laboratories Division at Baltimore has been redesignated the Research Division.

• **Aeroquip Corporation** has published a new 12-page catalog listing hose, fittings, elbow assemblies, and self-sealing couplings. Copies are available by requesting *Catalog Bulletin 240*, Advertising Dept., Aeroquip Corporation, Jackson, Mich.

• **Aircraft Radio Corporation** has announced plans for another enlargement of its engineering laboratory. The firm scheduled occupancy of another new building for the end of May. . . . A dual-purpose antenna is described in a new brochure. It contains standing-wave ratios and radiation pattern diagrams, and descriptions of the Type A-13B VHF Navigational Antenna, designed for use on all types of aircraft.

• **Allis-Chalmers Manufacturing Company** has published Bulletin 20X6234C, *Longer Belt Life for Your V-Belt Drives*, which may be obtained by writing the firm at Milwaukee.

• **Allison Division, General Motors Corporation,** has opened a new facility for minor overhaul of Model 501 prop-jet engines and for assembly and repairs on Aeroproducts 606 propellers, at 3216 Vanowen Street, Burbank.

• **American Airlines, Inc.,** has reorganized its flight department to permit more time for planning procedures and policies for the future. The program calls for decentralization of the department's activities in various national field offices.

• **Avien, Inc.,** has published a new brochure describing an overheat-time recorder for aircraft jet engines, available from the firm's Product Supervisor, Temperature Instrumentation, 58-15 Northern Blvd., Woodside 77, N.Y. . . . Ernest T. Donohoo has been appointed Central Region Manager.

• **Beech Aircraft Corporation** has announced plans to remanufacture Army L-23 command transports which will reappear as L-23D's and have new electronics gear, accessories, systems, interior styling, and other features. New 340-hp. supercharged Lycoming engines will be installed.

• **Bendix Aviation Corporation,** Friez Instrument Division, has announced plans for a new manufacturing, engineering, and research facility—66,000 sq.ft. in area—to be added to its existent plant . . . . Radio Division has announced it will supply extensive air-borne electronic equipment installations for new Bristol Britannia transports ordered by Northeast Airlines. The division also reports it has perfected new lightweight communications and navigation equipment for business planes which saves 46 per cent of space and 33 per cent of weight used by corresponding heavier units.

• **Boeing Airplane Company,** Wichita Division, has scheduled installation of two J-75 jet engines (for test purposes) on the original XB-52. One J-75 will replace two J-57's on the outboard pod of each wing.

• **Chance Vought Aircraft, Incorporated,** engineers have modified a pilot ejection seat which they report will reduce the number of back injuries suffered during hard landings. A frangible foamed plastic

seat cushion and a stainless steel strap in the rear of the ejection seat reduce the g-forces on a pilot during sudden, violent contacts.

• **Douglas Aircraft Company, Inc.,** is proposing a new utility assault aircraft to the Navy. The firm reports that its Model 1906A has been designed specifically for fleet aerial resupply and Marine light assault missions, for operation from carrier decks or short, unimproved fields, and for a speed ranging from 270 to 315 m.p.h. Work on it is in the advanced design stage . . . . Engineers have developed a device that prevents jet engines from picking foreign objects off the ground. It dissipates a vortex formed ahead of jet engines before it can suck up objects . . . . Sale of two DC-6A aircraft to Hunting-Clan Air Transport, Ltd., of Great Britain also was announced.

• **Fairchild Engine and Airplane Corporation,** Stratos Division, has developed a solenoid to arm missiles in a high-performance fighter which operates unpressurized to very high altitudes . . . . The Aircraft Division held a 3-day mock-up and specification meeting for 39 pilots and officials of firms purchasing or evaluating the F-27 . . . . Sherman Fairchild & Associates, Inc., has moved from Rockefeller Plaza, New York, to 580 Midland Ave., Yonkers, N.Y.

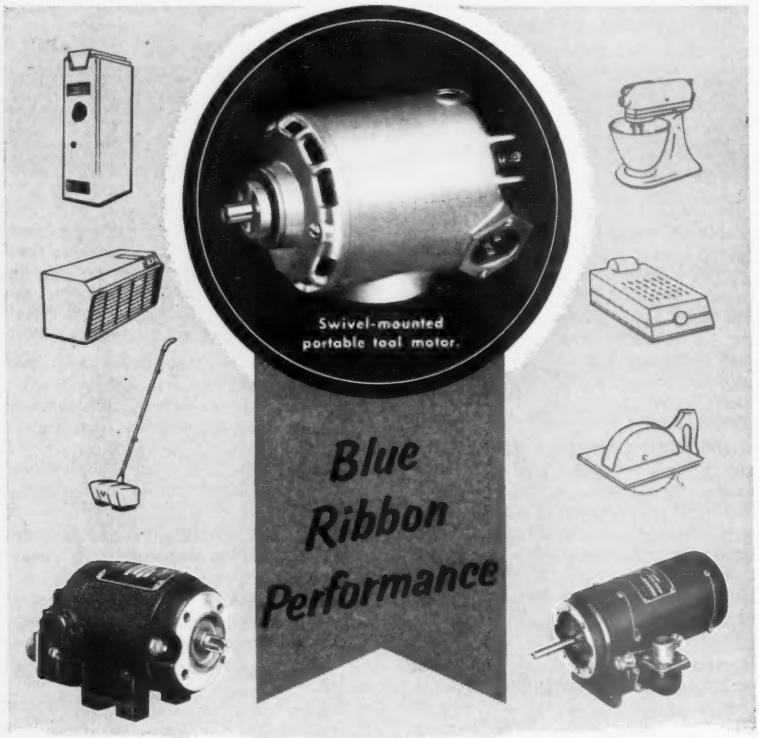
• **Flight Refueling, Inc.,** has developed a small, lightweight refueling unit in cooperation with North American Aviation, Inc., for installation under the wing of the F-100D Super Sabre and probe and drogue refueling of "buddy" F-100's.

• **General Dynamics Corporation,** Convair Division, has announced that B-58 flight-test operations have been extended to Eglin Air Force Base Armament Center and Kirtland Air Force Base Special Weapons Center. . . . A new sound laboratory is being set up in San Diego to test acoustical properties of the 880 jet transport. Some 50 executives, engineering, and contract officials of Trans World Airlines, Delta Air Lines, and Convair attended the 880's first mock-up conference. Wind-tunnel tests and resulting design refinements have boosted maximum cruising speed to 615 m.p.h., the firm reports . . . . A $3 million renovation plan for Convair's two main engineering buildings at San Diego has been announced. . . . Convair-Astronautics, builder of the Atlas missile, has been made a full operating division within Convair.

• **General Electric Company** has begun construction of four flight-test hangars for the Air Force at Edwards AFB, Calif. The firm also has opened a second European office at Geneva, Switzerland, to handle technical service of its jet engines and aircraft accessories . . . . Chemical & Metallurgical Division scientists have announced discovery and development of Lexan, a polycarbonate resin, reportedly tough enough to replace metals in many applications. The division's Metallurgical Products Department has developed a new 3-in. diameter, disc-type discharge varistor assembly for direct installation in electrical circuits. The department staff also announced four new engineering appraisal kits said to provide the electronic engineer with greater latitude in determining which thermistor is applicable to his circuitry problems. The division's Silicone Products Department has announced construction of a new product and process development laboratory and further expansion of other facilities at Waterford, N.Y. . . . Defense Electronics Division announced organization of a guided-missile nose cone team for the Missile and Ordnance Systems Department (to be called the Nose Cone Section). . . . Apparatus Sales Division has published through its Distribution Assemblies Department a bulletin describing a new combination feeder, plug-in busway. . . . Engineers in the Aircraft Products Department report mothballs successfully maintain accuracy in extremely sensitive aircraft instruments. They devised a switch using naphthalene to turn on and off a small lightweight heater for instruments affected by temperature change. Napthalene was found to have an exact melting point and a definite rate of expansion and contraction between melting and freezing points.

• **General Precision Equipment Corporation,** General Precision Laboratory Incorporated, has announced development of a telescopic alignment kit for use by air-frame manufacturers with the firm's Model PD-150 closed-circuit television system. The kit reportedly increases efficiency and accuracy in tooling problems calling for precision optical alignment.

• **G. M. Giannini & Co., Inc.,** has developed a new, low-torque potentiometer,



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BOEING 707
starts a new era of Jet Transportation

America's first jet airliner recently streaked across the country in three hours and 48 minutes for a new transcontinental passenger plane record. The plane carried 52 people and made the 2,325 miles from Seattle to Baltimore at an average speed of 612 miles an hour at altitudes of six miles and above.

To control such fast planes at high altitudes requires control cables designed to fit the application. Engineers at American Steel and Wire have cooperated with airplane manufacturers in designing American Tiger Brand Control Cables that meet the most rigid specifications. These cables have high strength, high resistance to bending fatigue, minimum stretch and the superior flexibility of Excellay Preformed Construction. They are used on all types of planes from fighters to heavy bombers. Write for complete information or call our nearest sales representative.

The Boeing 707 jet airliner ushers in a new era of fast transportation when it will be possible to have lunch in New York and dinner in San Francisco.

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USS American Tiger Brand Aircraft Control Cables

UNITED STATES STEEL

Model 85151 Minitorque, only 1 in. in diameter. It features a heavy-duty (0.126 in.) stainless steel shaft mounted on miniature shielded ball bearings. It weighs 0.6 oz.

• **The B. F. Goodrich Company** has begun testing new fuel cell materials and designs for military aircraft at its recently completed fuel cell development laboratory. The laboratory is operated by the Aviation Products Division, Los Angeles.

• **The Goodyear Tire & Rubber Company, Inc.,** Aviation Products Division, has developed a series of rubber barrel-shaped cylinders for cushions under an aerial drop platform designed for paratrooper heavy equipment. Eight air bags are inflated by uprushing air during parachute descent and absorb shock when the platform reaches the ground.

• **Walter Kidde & Company, Inc.,** has published a new brochure on auxiliary power systems for missiles or manned aircraft. The systems provide electric, hydraulic, or other power to actuate critically important devices, the firm says.

• **Kollsman Instrument Corporation** announced that its KS-54 Cabin Pressure Control System will be standard equipment for the Fairchild F-27 and that its Integrated Flight Instrument System (Kifis) will be standard on the Convair 880.

• **Koppers Company, Inc.,** has announced the following appointments: S. H. Fedan, Assistant Department Manager and Manager of Aviation Sales; Richard R. Audette, Assistant Chief Engineer; Norman J. Ely, Project Engineer; and George A. Levis, Aviation Sales Engineer—all of the Industrial Sound Control Department, Metal Products Division.

• **Lear, Incorporated,** Grand Rapids Division has announced development of control force sensors which reportedly augment the naturalness of control from the stick with the smoothness and precision of automatic flight controls . . . . Lear-Romec Division has developed a high-capacity water injection pump for gas-turbine engines. The division reports its Model RR11610 is rated at 180 gpm at 35 psig minimum discharge pressure.

• **Lockheed Aircraft Corporation** has announced that it is building a jet utility trainer-transport for use by the Armed Forces at its Burbank Calif., Division plant . . . . Georgia Division has announced that a new type of aircraft will be built at its Marietta plant within the next 3 or 4 months; it "might be a small jet transport," but it was not said whether this would be identical with the aircraft under construction at Burbank . . . . Latest report on the C-130 Hercules states that it (1) lifted a world-record 111,000 lb. gross weight from ice-covered Lake Bemidji, (2) landed in 1,425 ft., and (3) took off in 985 ft.

Lockheed Aircraft Corporation reported from its Georgia Division that the C-130 Hercules has lifted a world-record gross weight of 92,976 lbs. from snow-covered ice on Lake Bemidji, Minn. The test (shown in the picture) was made for the Air Force. The firm says the take-off run was 985 ft. from a surface of 12-in.-thick snow and 24-in.-thick ice.

• **Manning, Maxwell & Moore, Inc.,** Aircraft Products Division, has developed a new 4-oz. hydraulic amplifier which the firm reports operates without the need of an amplified signal input. It has been designed for use in control systems requiring high reliability and sensitivity.

• **The Martin Company,** RIAS, Inc., subsidiary, has completed a preliminary design study of a space vehicle which will permit the recovery of nuclear emulsions exposed for considerable time to primary cosmic radiation. This is part of an overall study on the feasibility of recovering the scientific pay load of rocket research vehicles which have spent much time out of the atmosphere. Scientists are considering arrangements for conducting a cooperative research program using a three-stage rocket. Design study shows that the pay load, 150 lb., can be projected more than 2,000 miles into space with available rocket components. One third of the weight will be scientifically useful; the other two thirds will provide structure and protection for recovery.

• **Norden-Ketay Corporation** has manufactured a new line of motor tachometers and tachometer generators for use in high-accuracy computers and servosystems with application to guided missiles, navigation equipment, fire control computers, and bomb directors. The firm reports that it is also producing new floated rate gyros with temperature control volumetric thermostat, signal pickoff, ruggedness, reliability, and precision.

• **North American Aviation, Inc.,** Autonetics Division, has developed an Instrument Display Projector—a compact device that reportedly provides at a glance essential information to pilots for completing an instrument landing, while at the same time allowing visual contact outside the airplane. Components are a cathode-ray tube (1.5 in. diameter), a mirror system, collimating optics or optics that make light rays parallel, and a trichoric combining glass that uses a color contrast principle to enhance definition of the reflected image. The division also has established an eastern branch office in Room 412, Cafritz Building, 1625 I St., N.W., Washington 5, D.C., for coordination of needs of military and civilian agencies of the Government. Norman P. Hays is in charge of the office.

• **Northrop Aircraft, Inc.,** has announced a new type of tensile coupon "gage length" scribing fixture and an accessory device which holds fractured coupons for elongation measurements. The firm also has established a new division, Northrop International, with J. Gilbert Nettleton, Jr., corporate Vice-President, assigned management responsibility. All overseas programs of the parent company will be handled by the new division.

• **Pan American World Airways, Inc.,** has begun daily Tourist service between New York and Nassau, Bahamas.

McDonnell Aircraft Corporation has announced completion of the first test flight of its F-101B Voodoo, third version of the Century Series fighter. The newest model is a two-seater—the extra seat for a radar observer—designed to serve a dual purpose: identification of unknown aircraft and destruction if it is hostile.

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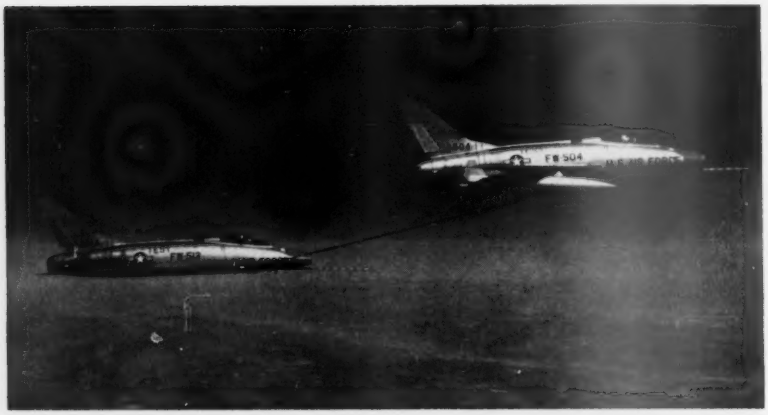
UNION CARBIDE

In the world's largest supersonic wind tunnel at Lewis Flight Propulsion Laboratory, N. A. C. A., Cleveland, Ohio, huge stainless steel plates withstand wind velocities of 2300 mph—more than three times the speed of sound.

The terms "Electromet" and "Union Carbide" are trade-marks of Union Carbide Corporation.



"Buddy System" refueling of North American Aviation's F-100 Super Sabre over the Mojave Desert is shown for the first time. The system was developed for the Air Force by North American and Flight Refueling, Inc., and enables the F-100 to carry a heavier bomb load. It also makes possible emergency refueling of planes that return to base low on fuel.

• **The Parker Appliance Company** has developed three new low-shrinkage silicone rubber compounds for O-rings and other molded parts. The firm reports that the new compounds can be handled in standard molds, as used for regular synthetic rubber compounds, and come out to AN size and tolerance.

• **Republic Aviation Corporation** has sponsored the Alouette II, French gas-turbine helicopter, on an American tour. Made by Sud-Aviation, the five-place, medium-range helicopter has been demonstrated to all the Armed Forces branches and at the American Helicopter Society's annual convention. Republic has been licensed to manufacture the Alouette here.

• **Servomechanisms, Inc.,** has announced formation of a new component division specializing in vacuum film products. Known as the Vacuum Film Products Division, it is located at El Segundo, Calif., and is managed by David W. Moore. The firm also reports that ground has been broken for a new plant in Westbury, L.I., N.Y., where electronic control equipment will be manufactured.

• **Shell Oil Company** has developed a special grade of kerosene, Shell UMF Grade B, to propel the IGY earth satellite's first-stage rocket.

• **Sperry Gyroscope Company Division of Sperry Rand Corporation** has announced what it calls a "revolutionary" radio navigation system, CYTAC, said to be ten times more accurate than any other known system at equal ranges. The system improves and differs from Loran through use of lower frequency transmission. According to the firm, it requires only 15 ground transmitters to provide a complete, 24-hour, all-weather air and sea navigation umbrella over the entire United States and adjacent sea lanes. The firm also has announced development of the C-11 Gyrosyn, reportedly six to 15 times more accurate than gyro compasses in general commercial and military use and twice as precise as special purpose military equipment weighing three times as much.

• **Stanley Aviation Corporation** has made plans for the design and fabrication of control systems for nuclear reactors at a plant recently expanded and equipped. A totally separate prototype shop has been organized to handle numerous experimental and development projects.

• **Systems Laboratories Corporation** celebrated its first birthday on June 1, the date it occupied its new headquarters facilities at Sherman Oaks, Calif.

• **Thiokol Chemical Corporation** has announced that it is supplying solid propellant sustainer units for the Nike-Hercules and that it has developed all five solid propellant propulsion units used in the Lockheed X17 re-entry test missile.

• **Thompson Products, Inc.,** has announced the election of H. A. Shepard, Operations Vice-President, as a Director of the firm. Whitmell T. Rison, Replacement Division Manager, was elected a Vice-President.

• **Union Carbide and Carbon Corporation,** National Carbon Company, has published a new catalog section, *Brushes for Aircraft Equipment B-1705,* available at 30 E. 42 St., New York 17, N.Y. Another new bulletin, *A Guide to the Selection of "Karbate" Impervious Graphite and Resin Base Cements for Corrosive Services,* also is available.

• **United Aircraft Corporation,** Hamilton Standard Division, has placed in production a hydraulic pump said to be capable of operating at high temperatures while providing needed auxiliary power to control supersonic aircraft. Four of these new pumps power the B-58 hydraulic system. The division also is manufacturing a specially tailored, three-bladed propeller for advanced versions of the Super-Constellation. It incorporates a stronger hub and "beefed-up" solid aluminum-alloy blades. . . . Pratt & Whitney Aircraft Division's J-57 and J-75 engines have been certified by the CAA for commercial use by air lines. An ARDC test on the J-57 had it operating 1,000 hours without overhaul, the equivalent of more than 20 flights around the world.

• **United Air Lines, Inc.,** has leased a "650" magnetic drum computer to prepare financial statements and process payrolls for 17,000 of the firm's 20,000 employees.

• **Vickers Incorporated** has moved its Aero Hydraulics Division to a new plant at 3201 Lomita Blvd., Torrance, Calif.

• **Western Gear Corporation,** Electro Products Division, is manufacturing a new 400-cycle, 200-volt, three-phase, two-speed constant torque motor. The firm also has made available a 30 V.D.C. permanent magnet governed planetary-type gearmotor, Model PG5B81RP65.

• **Westinghouse Electric Corporation** announced that it is designing a nuclear propulsion plant for an atomic-powered submarine capable of carrying and firing guided missiles. . . . Electronic Division engineers have developed a radar track-while-scan system which automatically tracks up to 72 targets in three dimensions . . . Air Arm Division's Aero 13F armament control system had its first showing at the Naval Air Weapons Meet. It is a cylindrically packaged unit consisting of the AN/APQ-50 radar, the Aero 5B Armament Control Director (computer), and the AFCS MK-16 Optical System.

IAS SECTIONS

Atlanta Section

Research scientist Richard T. Whitcomb of Langley Aeronautical Laboratory, NACA, discussed "Area Rule and Its Application to Airplane Design" at the March 7 meeting. Mr. Whitcomb originated the area rule concept.

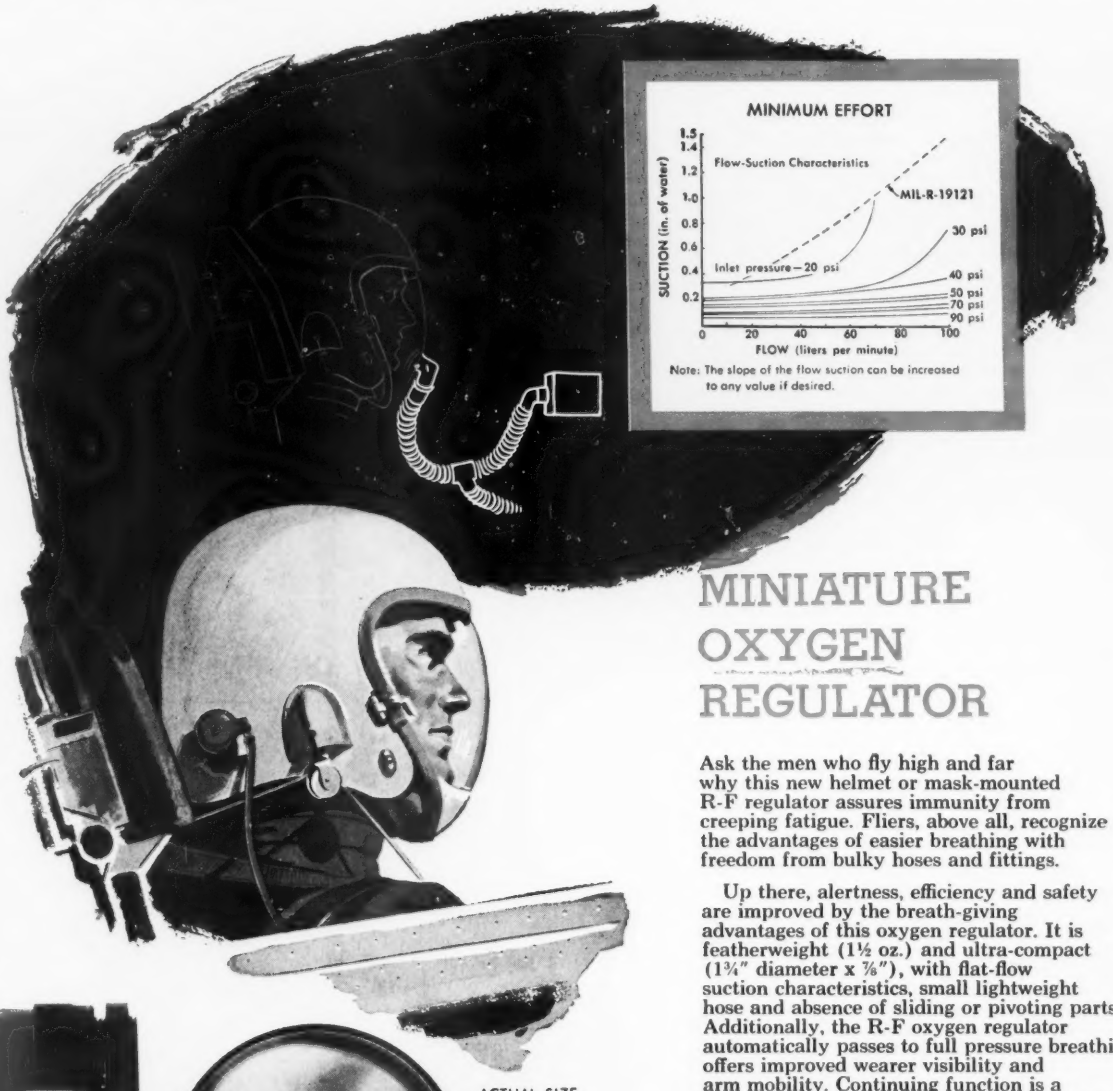
The zero-lift drag rise of a wing-body combination at transonic speeds is a function of the longitudinal distribution of the cross-sectional area of the configuration, he said explaining the rule. This conclusion evolved from study of schlieren photographs of shock-wave patterns taken during investigations of wing-body interference at Langley.

From a study of these data, it was deduced that indenting the body would reduce drag of a wing-body configuration at transonic speeds. This proved true for all types of wing and, in addition, increased Mach Number of configurations. He went on to describe some research investigations aimed at extending beneficial effects of body indentation to supersonic Mach Numbers.

Mr. Whitcomb concluded by stating that the upper limit of area rule applications is about Mach 2. This limit was arrived at because area rule is based essentially upon linearized flow theory. At higher supersonic Mach Numbers, the flow is no longer defined by Mach angle.

▶ Grover Loening spoke on "Air Freight in Competition With Motor Transport" at the February 7 meeting.

where altitude builds FATIGUE



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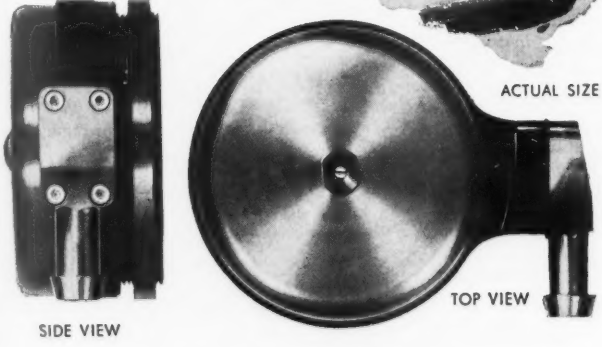

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From his analyses, Mr. Loening concluded that a 20,000-lb. pay-load cargo plane with a 350-m.p.h. cruising speed and a 35-m.p.h. (or less) landing speed, produced in quantity at about $300,000 cost, could compete with motor transport at its own price. When this aircraft is manufactured, he estimated air-cargo traffic will increase fiftyfold over present volume. (For the complete article, see pp. 70–73, this issue.)

CLAUDE V. WILLIAMS, *Secretary*

Baltimore Section

Captain E. B. Roberts, Chief, Division of Geophysics, U.S. Coast and Geodetic Survey, spoke on "General Aspects of the International Geophysical Year" at the March 7 meeting at the Baltimore plant of The Martin Company.

Captain Roberts covered a general field of IGY subjects. A question and answer period followed the talk.

During the business meeting, proposals for changes in the constitution and bylaws were received.

▶ Two representatives from Vickers-Armstrongs and Capitol Airlines retold "The Viscount story" at the February 7 meeting at the Air Arm Division of Westinghouse Corporation.

The talk was supplemented with a film tracing construction and operation of the aircraft.

RONALD G. CLANTON, *Secretary*

Chicago Section

James Delano discussed problems encountered in transonic and supersonic wind-tunnel testing before 150 students, members, and guests at the annual student meeting, March 6.

Student branches of the University of Illinois, Navy Pier Branch; Illinois Institute of Technology; and The Aeronautical University participated.

G. Huelsbeck, Chief Experimental Test Pilot, McDonnell Aircraft Corporation, also spoke on test problems in high-altitude and high-speed flight.

Mr. Delano reviewed wind-tunnel testing from the Wright brothers to the present. Using films and slides, he explained the area rule concept and cambered wing, both the result of wind-tunnel testing.

Mr. Huelsbeck referred to development history of the F-3H Demon to point out flight-test problems. This aircraft, intended as an interceptor, was requested by the Navy to serve as a general-purpose fighter about the time the prototype flew. The request resulted in many drastic design changes, creating problems in the area of stability and control. The problems were solved, and the aircraft was accepted by the Navy.

R. F. HUNTER, *Secretary*

Hagerstown Section

Paul Garber spoke on "The History of Aeronautics" before 120 members and guests at the February 14 dinner meeting. Mr. Garber is Head Curator, National Air Museum, Smithsonian Institute.

Dr. Garber's comments were centered on the Wright brothers. He illustrated his talk with slides of their accomplishments.

He said many historical items connected with aviation are too large to be stored in the Smithsonian building. These things are at the mercy of the elements, and he is devoting all his efforts toward remedying this situation, Dr. Garber said.

Plans for a National Air Museum building are awaiting Congressional approval. Two sites for the building are being considered—Fort Myer, Va., and College Park Airport. Dr. Garber concluded with the hope that Congress will act soon on the project.

R. W. BRADHAM, *Secretary*

Flying a VTO

Hampton Roads Section

James F. Coleman spoke on "Vertical Riser—An Engineering Test Pilot's Report" at the March 12 meeting. Mr. Coleman is with the Customer Relations staff of Fairchild Engine and Airplane Corporation.

First pilot to fly successfully the Navy's XFY-1, he summarized some of the problems involved with this VTO fighter. He illustrated his talk with films of the XFY-1 and a delta wing aircraft.

He listed problems encountered, such as flying the aircraft in the statically unstable regime following lift off, the transition from vertical to horizontal flight, placing the aircraft in an attitude for landing, and judgment of vertical movement. The pilot has a tendency to overcontrol when first flying the machine vertically after take-off. This results in marked horizontal movements and undesirable attitudes of the aircraft. Mr. Coleman said with practice this tendency can be overcome.

During transition from vertical to horizontal flight the pilot must perform several physical acts simultaneously. He must look over his shoulder to observe position of the ground, fly the airplane through the transition, and adjust the trim—all while his seat is rotating. He described the operation as "rubbing one's stomach and patting one's head while doing a third similar action at the same time."

Mr. Coleman said he believes an automatic pilot of some kind ought to be incorporated into the airplane to aid in accomplishing this difficult maneuver.

To land the VTO, the pilot pulls back on the stick and cuts the throttle simultaneously, exactly opposite to what he has learned throughout his flying experience. Eventually, the pilot learns to accomplish this action without extreme misgivings, he said.

At a distance of more than 200 ft. from the ground, there is no perception of vertical action. Because of this, it is a problem to bring the aircraft down at a proper rate of speed for a smooth landing. Several ideas were attempted for measuring accurately the rate of descent or ascent.

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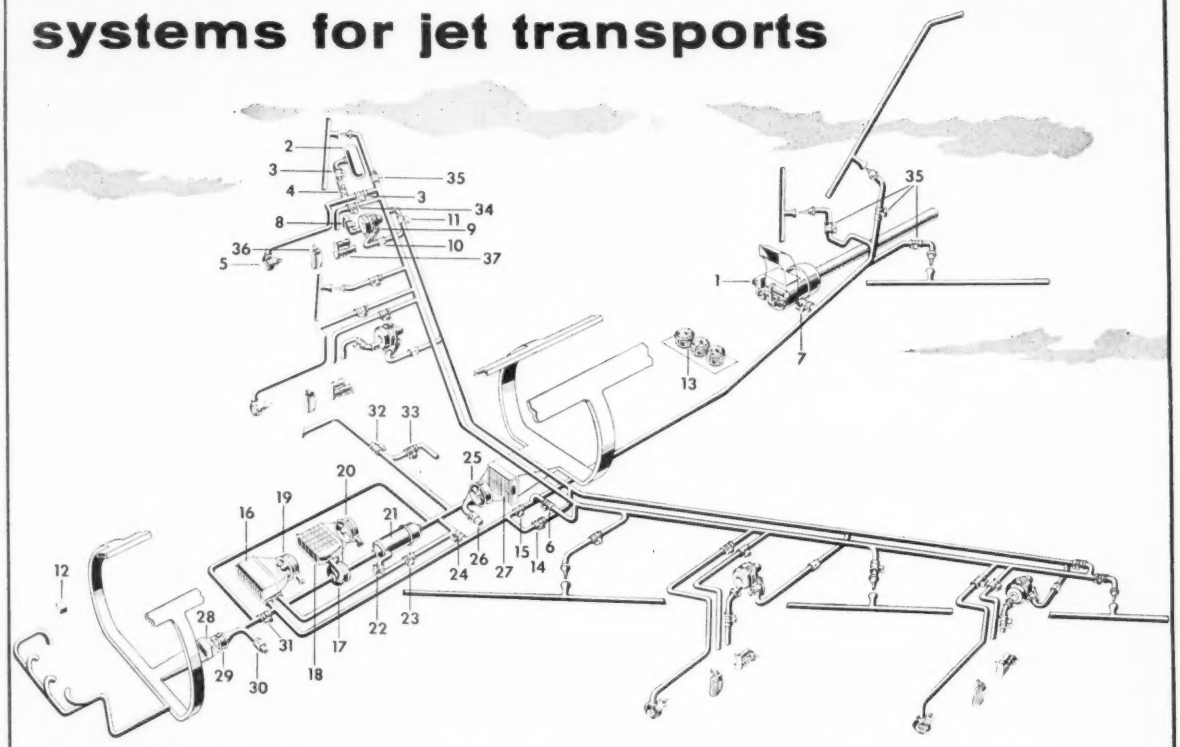

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14. Cabin Air Conditioning and Pressurization Shut-off Valve
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17. Bootstrap Refrigeration Unit
18. Secondary Heat Exchanger
19. Primary Heat Exchanger Cooling Air Fan
20. Secondary Heat Exchanger Cooling Air Fan
21. Water Separator
22. Water Separator Anti-icing Control Valve
23. Turbine By-pass Valve
24. Cabin Hot By-pass Valve
25. Cabin Recirculating Fan
26. Cabin Recirculating Fan Check Valve
27. Cabin Electric Heater
28. Flight Station Electric Heater
29. Flight Station Recirculating Fan
30. Flight Station Recirculating Fan Check Valve
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The Minta Martin Lecture was presented before members of the Boston Section on March 19. Shown at the meeting are *(left to right)* S. Paul Johnston, IAS Director; I. E. Garrick (guest speaker), Hunsaker Professor of Aeronautical Engineering, 1956–57, Massachusetts Institute of Technology; C. S. Draper, Head, M.I.T. Aeronautical Engineering Department; and Edward Dashefsky, Chairman, Boston Section.

Neither sensitive glider-type rate indicators nor Doppler radar were completely satisfactory. A more satisfactory procedure employs an outside observer to check the position of the aircraft against a grid. This worked until the pilot flew the VTO outside the field of observation of the outside observer.

Mr. Coleman concluded with the opinion that many problems associated with the VTO aircraft may be overcome and that it can be made a highly satisfactory operational machine.

RICHARD T. WHITCOMB
Recording Secretary

Sikorsky Story

Rocky Mountain Section

Igor I. Sikorsky (HF) spoke on "Helicopters of Today and Tomorrow" at the February 18 meeting in Wyer Auditorium, Denver. Mr. Sikorsky is Engineering Manager, Sikorsky Aircraft Division, United Aircraft Corporation.

He traced his aeronautical career from 1908, when he first learned about the flight of the Wright brothers and decided to make flying his life work. He left Russia for Paris in 1909, where he met Orville Wright.

Mr. Sikorsky described the scene at airfields near Paris as a tragedy of amateurs wasting their life savings and discarding businesses to spend their time developing (without knowledge or skill) ridiculous flying machines.

His first love, he said, was the helicopter, and during 1909 and 1910 he built two which would hover under their own power but were incapable of carrying a pilot. He felt at the time that neither materials nor knowledge were available to develop a successfully piloted helicopter. He turned to conventional aircraft and built two which flew successfully until crack-ups.

A methodical training program enabled Mr. Sikorsky to make successful 30-min. flights in a third aircraft by mid-1911. His thoughts turned toward development of a multiengined aircraft, which he thought would be more reliable, after engine failure caused another crash. He built the four-engined Sikorsky Grand in Russia in 1913. This aircraft was inspected by the Tsar, Mr. Sikorsky said, who encouraged him to continue his developments.

In 1914, he built a four-engined, 4-ton airplane with some of the earliest instruments—a ball-bank indicator and a speedometer made of a U-tube manometer indicator. This plane could fly with one engine dead, carry 16 passengers, and had a top-side balcony where passengers could stand while the plane flew at 65 m.p.h. This was the first aircraft to carry a machine-gun and the first to carry a 1,000-lb. bomb (in 1916), Mr. Sikorsky said. He was responsible for some 75 aircraft used by Russia in World War I. He left Russia in 1920 and built his first airplane in this country in 1923.

Mr. Sikorsky showed slides of other aircraft he developed—his first flying boat, sold to United Air Lines and Pan American Airways for transocean passenger service, and the S-42, whose range was 3,300 miles in the early 30's.

After 30 years with conventional planes, he returned to the helicopter in 1938. By 1940, he had developed and test-flown the VS-300, powered by a 100-hp. engine, which later set an endurance record. From this came the S-55, H-19, and S-56, which lifted 13,000 lbs., hit 6,500 ft. altitude, and flew 162 m.p.h.

He concluded with the observation that helicopters offer a unique advantage over conventional aircraft in their ability to lift heavy weights and carry bulky objects. He said he believes we will soon see crane helicopters capable of carrying 25 to 30 tons. But he does not believe VTOL aircraft will make airports unnecessary or will assume a major role in the overall development picture.

Mr. Sikorsky said development of both the true airplane and the true helicopter should be continued since remote location of airports that can handle high-speed true airplanes will be no great handicap provided the helicopter can find wide application in shuttle service from these airports to cities.

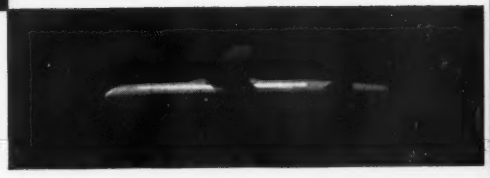
Mr. Sikorsky was accompanied to Denver by B. L. Whelan, Vice-President, United Aircraft Corporation, and Mrs. Whelan. Guests of the Air Force Academy, the party was taken on an air tour of the Academy grounds at Colorado Springs.

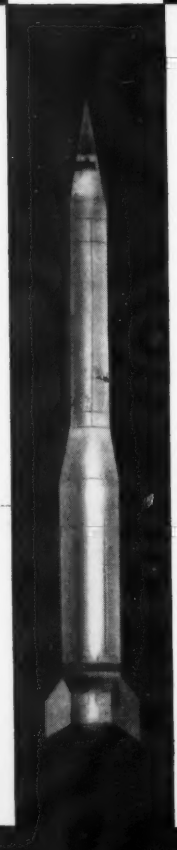
A. W. GILMORE, *Secretary*

Seattle Section

I. E. Garrick, Hunsaker Professor at Massachusetts Institute of Technology, was honored by 125 members and guests at the April 3 dinner meeting at the Olympic Hotel.

Igor I. Sikorsky (HF) spoke on "Helicopters of Today and Tomorrow" at the Rocky Mountain Section's February 18 meeting. Shown at the meeting are *(left to right)* B. L. Whelan, Vice-President, United Aircraft Corporation; Col. Paul Dane, Section Vice-Chairman; Mr. Sikorsky; and Rear Adm. A. F. Bonnalie, USN (Ret.), Director of Flight Training, United Air Lines, Inc.





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In 1946, development was commenced on the Martin MATADOR pilotless bomber for the Air Force... GORGON, a Navy test vehicle... and the VIKING series of high-altitude research rockets. Within two years these were followed by ORIOLE, an experimental air-to-air missile, and PLOVER, a target drone. More recent developments include LACROSSE for the Army... TITAN, the Intercontinental Ballistic Missile for the Air Force... and the launching vehicle for project VANGUARD, the earth satellite, undertaken with the Naval Research Laboratory as a major U. S. contribution to the worldwide science program of the forthcoming International Geophysical Year.

MARTIN

BALTIMORE · DENVER · ORLANDO

After the dinner, Professor Garrick delivered the Minta Martin Lecture, "Some Concepts and Problem Areas in Aircraft Flutter."

▶ Stanley H. Brewer spoke on "Vision in Air Cargo" at the March 6 meeting. He is Professor of Transportation at the University of Washington.

Professor Brewer, currently conducting an economic study on depth of the air-cargo market for Boeing Airplane Company's Transport Division, covered past, present, and future in air cargo. Pointing out the development of railroads and automobiles from passenger carriers to cargo carriers, he predicted a similar growth for air-cargo business. He said the earlier carriers required billions of investment before they began to pay off.

Although the economics of air traffic favor passengers, air mail, express, preferential mail, and freight in that order, the economics of the airplane are rapidly changing so that modern aircraft are large enough and fast enough to make cargo pay. Professor Brewer supported this thesis with many statistics and said that a tremendous amount of "vision" is called for on the part of industry and carriers.

He analyzed negative and positive factors involved and concluded that a period of rapid expansion in air cargo lies ahead. But the shortage of suitable equipment is acute, and new ideas in cargo handling will be required. Air cargo must be sold. The value of minimizing stock must be recognized by shippers as it currently is being exploited by the military. Professor Brewer predicted a potential of more than 20 billion ton-miles per year by 1965.

THOMAS V. DAVIS, *Secretary*

St. Louis Section

Homer E. Newell, Jr., of the Naval Research Laboratory, discussed "The International Goephysical Year Earth Satellite Program" at the March 5 specialist meeting. Dr. Newell is Superintendent, Atmosphere and Astrophysics Division.

He reviewed plans for launching the satellites, the program objective, procedure to be followed, and method of tracking. A three-stage rocket will carry the 20-in. sphere from Cape Canaveral, Fla. He said program scientists hope a 35-deg. orbit of inclination can be achieved, with perigee no less than 200 miles.

Tracking will be both optically and by radio, using the Naval Research Laboratory Minitrack system. Plans call for participation of amateur astronomers in the optical tracking program and radio amateurs to help radio tracking. Measurements will be telemetered through the Minitrack r-f link. Computing centers will compute the orbit and analyze tracking information for geodetic studies and to determine upper air densities.

▶ Naval aircraft operational requirements were explained at the February 27 meeting by A. Hyatt, Research Analysis Officer, Naval Bureau of Aeronautics. Mr. Hyatt is in charge of the Research, Evaluation, and Airframe Design Sections at BuAer.

He described factors which influence new operational requirements—evaluation of enemy potential, revised tactical and strategic objectives, scientific and technological discoveries, state of the art, and industry production capabilities. He defined BuAer's role through its sections. He emphasized that although there are formal channels within the organization charged with developing operational requirements, their actual concept and definition is frequently anything but a formal and orderly process. By its very nature, operational requirements must be flexible enough to absorb all the necessary inputs from research and development, fleet operations, supply and maintenance, military intelligence, production, and fiscal groups.

Basic ideas or concepts often originate in groups outside those specific to operational requirements. The final formal statement is usually the result of a large amount of give and take between several diversified groups.

WILLIAM J. BLATZ
Recording Secretary

Texas Section

M. F. Mayer discussed "Aircraft Defense Systems" at the March 13 specialist meeting. Mr. Mayer is associated with Emerson Electric Manufacturing Company.

He reviewed the history of aircraft armament and said the basic problems of killing or defending an aircraft have not changed. But the degree of difficulty in solving these problems has increased fantastically, he said. Current aircraft

For long life under extreme conditions of shock, vibration, corrosion, humidity and temperature

Bendix W TYPE

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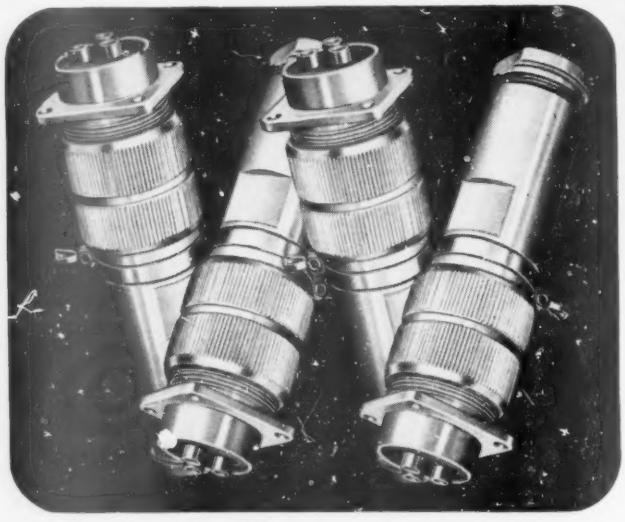

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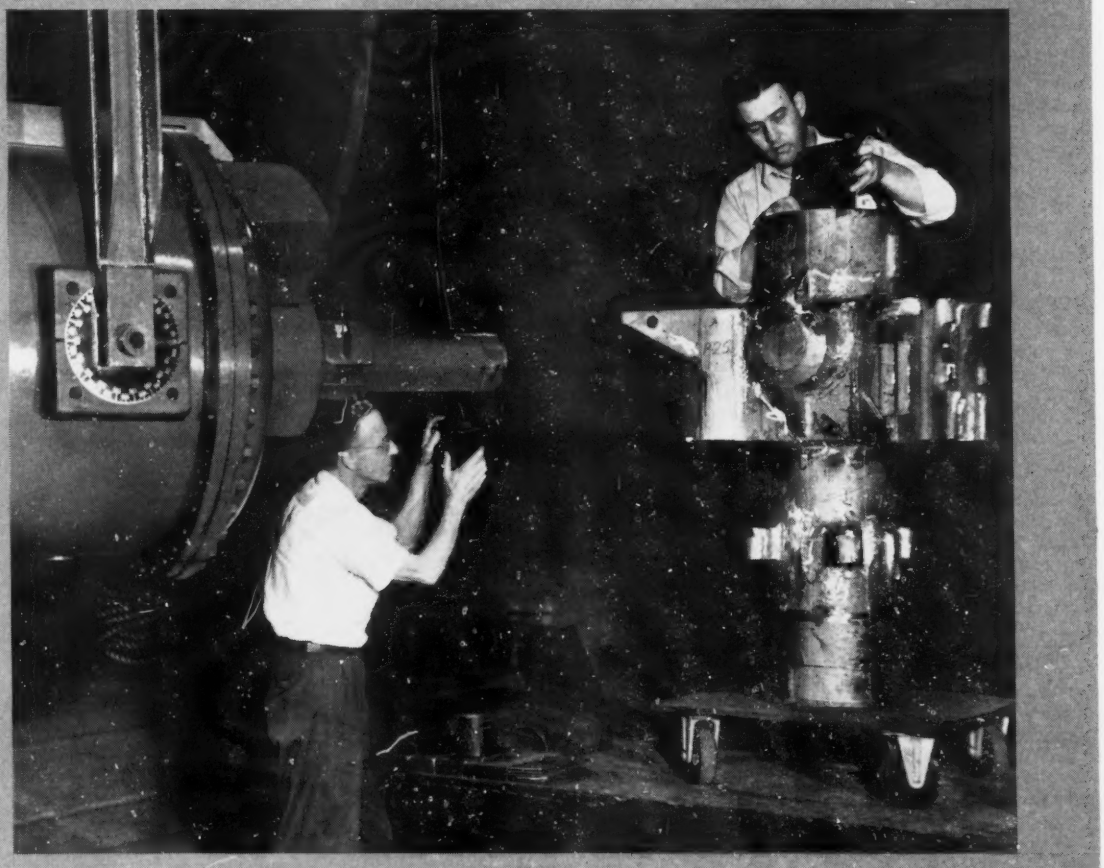

Watchdog on mounting costs

PRICES of common materials keep going up. Many new alloys are costly. Hence, rough castings become more expensive.

Even more, the cost of machining time keeps mounting. No one can afford to have it wasted by waiting for the tool to locate a void or defect.

So now is a good time to re-examine the importance of radiography. To suppliers it gives the assurance that only a quality product is delivered. To processors it gives the confidence that man and machine time will be productive—not wasted.

Today, million-volt x-ray equipment radiographs heavier parts with shorter exposures. The use of radioactive isotopes makes possible a radiographic department at moderate cost. And the new Kodak Industrial X-ray Film Type AA—with up to twice the speed of the previous film—widens the scope of all radiographic equipment.

If you would like to know how radiography can save you money—how it can keep the quality of castings high—have a serious talk with your Kodak x-ray dealer or Kodak technical representative.

EASTMAN KODAK COMPANY
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TRADE MARK

speeds have made the time involved in aerial combat so short that accuracy and fire power have become a premium more than ever.

Mr. Mayer covered the problems of building a complex fire control system for minimum weight and maximum effectiveness and pointed out the major parameters and their relationships.

An audience discussion centering on dynamic problems of turret control, the effects of gunfire frequencies, and structural elasticity followed the talk.

A. T. CLEMEN, *Secretary*

Transport Trends

Washington Section

George T. Worley, Chief of Advanced Design, Douglas Aircraft Santa Monica Division, spoke on "Future Trends in Air Transportation" at the March 12 meeting. Stuart G. Tipton, President, Air Transport Association of America, was Honorary Chairman.

Mr. Worley's paper covered a time-span from the present to 1970. Transport types of greatest utility, whether commercial, military, cargo, or passenger, are foreseeable considering the state-of-the-art and historical development, he said. Predictions beyond 1970 have less value because of the number of unforeseen types possible.

Much progress in aviation has started with a military speed record, eventually extended to commercial transportation. Useful aircraft have followed records in the order of fighters, bombers, and transports. But no transportation system can develop solely on the basis of speed. Its growth depends on the best balance of trip time (speed and availability), safety, comfort, range, and economy.

Mr. Worley discussed these factors in relation to subsonic and supersonic transports, application of turbojet and propjet engines, nuclear power and rockets, and STOL and VTOL aircraft.

He drew the following conclusions:

(1) Commercial air transportation will probably rely almost entirely on subsonic aircraft through the 1960's because of the limited range and high operating costs of supersonic aircraft.

(2) Turboprop engines are superior where short field lengths are required and high speeds are not of primary concern —e.g., cargo aircraft.

(3) Turbojet engines are superior if field length is not restricted or is consistent with the range to be flown and if high speed is desired.

(4) STOL aircraft will probably be used to satisfy needs for local service transportation. These appear superior to VTOL in safety, cost, and requirement for only modest airport facilities.

(5) Nuclear power will be adapted for use in large transport aircraft by 1970 but probably only for the military.

(6) Long-range rockets will serve no useful transportation purpose by 1970 since pay load is severely limited by the amount of fuel needed. Limited pay load combined with high fuel cost would produce completely unacceptable unit operating costs.

C. L. DESMOND
Secretary-Treasurer

ARDC Draws 500

Wichita Section

Nearly 500 members and guests attended a specialist meeting on "ARDC Command Briefing for Industry," presented March 15 by Lt. Col. Carlo R. Testi, USAF, Assistant Executive Officer, ARDC.

A secret meeting was held early at Boeing Airplane Company's Wichita Plant, and a second meeting, for which invitations were issued, was held later at McConnell Air Force Base. The meetings were for technical, management, and Air Force personnel of McConnell AFB, Boeing, Beech, and Cessna companies, and the University of Wichita.

The briefing was intended to provide personnel with a comprehensive view of USAF's development program, ARDC organization, its mission in the Air Force, and its relation to industry. Future technical planning of the ARDC was discussed, and special weapon systems were selected to demonstrate ARDC operation. Films of flight tests were shown.

▶ Allan J. Summers discussed "Guided Missiles and the Weapon System Concept" before 72 members and guests at the March 6 dinner meeting. Mr. Summers is Head of Preliminary Design Department, Missile Engineering Division, McDonnell Aircraft Corporation.

Mr. Summers said a guided-missile system is a complex of equipment and manpower organization, designed to perform a military mission. He explained how the weapon system concept works, beginning with the initial proposal to industry and continuing until delivery of the system, auxiliary training equipment, and system support equipment to the Government agency involved.

Mr. Summers pointed out that rapid advances in recent years in this field have caused a considerable spread of achievable guided-missile characteristics. As a result, industry finds it difficult to determine what type of missile to develop. This is solved by studying the problem through operations research techniques and design study group support. A system is conceived and then evolved through an overall development plan so that a weapon system will be available for use when needed.

After a question and answer session, Mr. Summers showed a 30-min. color film, *History of Aviation*.

EDWARD J. SULLIVAN, *Secretary*

STUDENT BRANCHES

Agricultural & Mechanical College of Texas

F. E. Weick, Head of the College Aircraft Research Center, discussed the design of the Ercoupe at the March 26 meeting. Mr. Weick designed and built the W-1 and W-1A over a period of 4 years when he was associated with the NACA in 1932.

These aircraft led to the design of the Ercoupe, first put into production in 1940. The W-1 had many advanced and special features for an airplane built in 1932. The plane was a pusher type with the tricycle landing gear. Built in Mr. Weick's one-car garage, it was flown from a field 50 ft. wide and 150 ft. long.

After the W-1 proved successful, it was followed by a slightly modified version, the W-1A. Mr. Weick explained how these two aircraft contributed to the design of the Ercoupe and why he employed tricycle landing gear. He illustrated his talk with slides and a scrapbook containing much of the history of the three planes. After the talk, students engaged Mr. Weick in a question and answer session.

LAWRENCE L. PATTON, *Secretary*

California State Polytechnic College

Virgil Upton, Project Engineer, Lockheed Aircraft Corporation, discussed the firm's Electra turboprop transport at the March meeting.

He said the Electra promises to lower maintenance cost through placement of hydraulic, electrical, and control units under the cabin floor for one-shot maintenance. Other characteristics of the Electra include simplified instruments, forward-folding landing gear, 375-m.p.h. cruising speed, and a 22,000-lb. pay load. The Electra also has a heated baggage compartment.

A nominating committee was formed for coming elections.

WAYNE M. FORD, *Reporter*

Georgia Institute of Technology

A representative from Aircraft Armaments, Inc., discussed the curriculum of the aeronautical engineering student at the March 4 meeting.

Basic sciences were emphasized. After the talk, members discussed the Student Paper Competition. One paper entitled "The Determination of the Induced Velocity in the Vicinity of a Lifting Rotor" is being written by Tim Robertson and Eugene C. Knox. Walter Castles is Faculty Adviser on this project.

Four new members were accepted conditionally into the Branch.

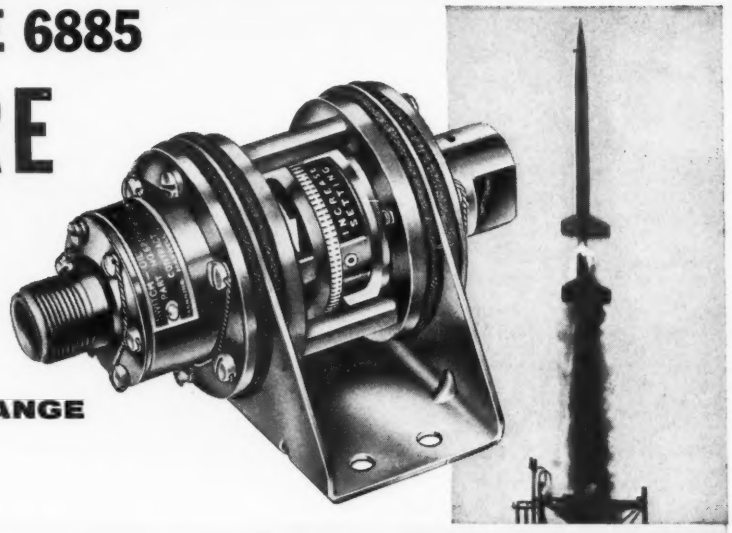
EUGENE C. KNOX, *Secretary*

Indiana Technical College

Clarence Grey of General Electric Company spoke on "The Engineer at

VERSATILE TYPE 6885 PRESSURE SWITCH

ONE BASIC DESIGN COVERS THE FULL RANGE OF APPLICATIONS



PRESSURE ADJUSTMENT RANGE	15 to 25 psia	0.25 to 4 psi	2 - 10 psi	10 - 50 psi	50 - 150 psi	150 - 500 psi	500 - 800 psi	600 to 3,000 psi	DUAL VERSION
ACCURACY OF SETTING (Under all test conditions)	±1 psi	±0.3 psi at 2.5 psi setting	±0.5 psi at 5 psi setting	±4% at 50 psi setting	±3% at 100 psi setting	±4% at 500 psi setting	±4% at 800 psi setting	±60 psi at 3000 psi setting	According to selected ranges
PROOF PRESSURE (Without setpoint drift)	500 psi	100 psi	750 or 4,500 psi (as required)	750 or 4,500 psi (as required)	750 or 4,500 psi (as required)	750 or 4,500 psi (as required)	4,500 psi	4,500 psi	250 psi
BURST PRESSURE	750 psi	450 psi	1,000 or 7,500 psi (as required)					7,500 psi	450 psi
TEMPERATURE RANGE	−75° F. to +250° F.								
VIBRATION	Up to 2,000 cps at 40 g. Exceeds MIL-E-5272A Procedure I								
OVERALL DIMENSIONS	Switch Proper—2" Diameter; Length 4⅜". Mounting Bracket to Suit Application								3½" wide 4⅜" long
WEIGHT	9 Ounces							10.5 Ounces	16 Ounces
ELECTRICAL RATING	30 Volts, 2.5 Amperes Inductive Load at 50,000 Feet								

This pressure actuated switch is particularly designed for aircraft, rockets and missiles to control electrical circuits whenever the system pressure deviates from a specified value.

Integral vibration isolation between mounting bracket and switch body contributes greatly to exceptional performance under vibration and shock conditions. Switch performance remains well within the tolerance limits given in the above table.

The Type 6885 incorporates an enclosed snap-action switch, actuated by the movement of a limp diaphragm. *External* adjustment of the control set-point is easy with the unit installed for operation. Mounting position does not affect calibration, nor can pressures above the switch adjustment range deflect the diaphragm. The switch is immune to standard aircraft fluids and to corrosive media like oxidizers, rocket fuels, or Mil-O-7808 oil. Only Teflon and aluminum contact the pressure medium.

An alternate Type 6885 Pressure Switch has two independent sensing and switch elements inside two housings with a single electrical connector and one pressure port. The Type 6885 can also be supplied with two electrical switches for double-pole, double-throw, non-simultaneous actuation.

The wide range of operating pressures and functional perfection under vibration obtainable with the Type 6885 Pressure Switch recommends it for a variety of airborne applications. For engineering counsel, please address your inquiry to our headquarters plant, Danbury, Conn.

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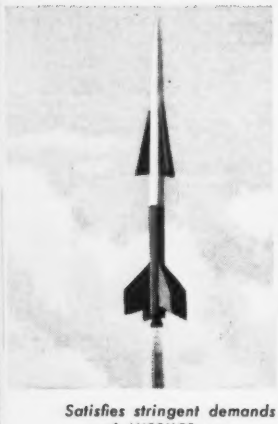
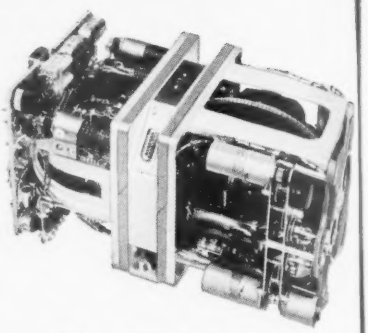
LOW ALTITUDE BOMBING SYSTEM—one example of how new 2-gyro system meets all-attitude stabilization requirements.



Satisfies stringent demands of MISSILES, too.

On ANTI-SUBMARINE WARFARE planes, new system eliminates DIRECTIONAL GYRO gimbal error and feeds error-free heading information.



Bendix 2-Gyro System weighs only 19 lbs. and measures only 6" x 6" x 12", including all amplifiers.

NEW! BENDIX 2-GYRO ALL-ATTITUDE CONTROL

basic reference for today's needs— saves 50% on cost and weight

This new 2-gyro system was specially developed by Eclipse-Pioneer to fill today's critical need for a *low-cost* master control reference combining vertical and directional gyros in continuous, high-precision performance through all attitudes and altitudes.

Extensive performance tests show the Bendix system's accuracy holds during rolls of 360° a second, loops of 80° a second and other high-rate maneuvers. Under test the new system has withstood 10G of vibration on its two horizontal and 1 vertical axes. Azimuth drift rate is 1° per hour maximum. Vertical drift rate is ¼° per minute maximum.

Bendix 2-Gyro All-Attitude Control will fully satisfy performance requirements in 90% of today's applications. And it offers the additional advantages of being half the cost and weight of 3-gyro systems.

This new 2-gyro system will be of interest in both commercial and military fields. Ask for details.

District Offices: Burbank and San Carlos, Calif; Dayton, Ohio; and Seattle, Wash.

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ADVANTAGES OF BENDIX 2-GYRO ALL-ATTITUDE CONTROL—

VERSATILE—*replaces all vertical and directional gyros used for indication, auto pilot control, navigation, fire control, radar stabilization and other functions.*

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NO GIMBAL LOCK—*functions with complete accuracy, even in extreme attitudes.*

ELIMINATES INTERMEDIATE AMPLIFIERS—*with new electrolytic switches handling all power erection direct.*

SMALLER, MORE RELIABLE, LONGER LIFE—*because of improved and transistorized servo amplifiers.*

MEETS REQUIREMENTS OF MIL-E-5272.

Eclipse-Pioneer Division

TETERBORO, N. J.

Bendix
AVIATION CORPORATION

General Electric" before 40 members at the March 26 meeting.

He explained the problems of the engineer with 3 or more years' experience behind him. The three items an engineer expects today are good wages, security, and good working conditions. He also explained how his firm meets this expectation.

▶ A film on *Crescent Wing Aircraft* was shown to 40 members at the March 12 meeting.

Plans for the annual banquet to be held at Orchard Ridge Country Club were discussed.

JACK D. BOCCALEONI, *Secretary*

Massachusetts Institute of Technology

"Selecting a High-Speed Plan Form for a Supersonic Bomber" was discussed by George C. Grogan at the March 12 meeting. Mr. Grogan is Senior Aerodynamics Group Engineer at Convair, A Division of General Dynamics Corporation.

He explained preliminary design stages of a modern military airplane, using a supersonic bomber as an example. Extensive study and research are necessary before a new type of aircraft can go into production, he said. First, a list of specifications is set up—range, speed, altitude, armament, size, bomb load, etc.—usually by the military. Aeronautical engineers must meet these specifications in the design. Research results are compared with the specifications, and aerodynamic, structure, and propulsion problems are turned over to appropriate design groups. The effects of wing shapes, weight and fuel capacity, and resultant compromises are discussed. Design locations are located and rechecked. New developments are continually incorporated into the design and the bugs are ironed out.

A film, *The B-58 First Flight*, was shown after the discussion.

WILLIAM TOWLE, *Secretary*

New York University

The Branch participated in a campus engineering day March 30, conducting tours through the Aeronautical Engineering Department and displaying aircraft designs by seniors.

The visit to department facilities included its wind tunnel and structural testing lab.

▶ Two Air Force officers, one a 1954 graduate of N.Y.U., spoke on rocket engines at the March 22 meeting.

Lieutenants Paul Lieberman and Alan Covington (Oregon State, 1956) described their jobs at the USAF Rocket Engine Test Laboratory at Edwards Air Force Base. They showed a film about rocket engines, described the work done at Edwards on missile engines, and told what a graduating engineer may expect in this kind of job.

▶ Films shown at weekly meetings during March were *Power by Wright*, from the Giannini Film Library, and *Lighter-Than-Air Rigid Air Ships*, a Navy training film.

MARVIN D. BARKAN, *Secretary*

ROCKET POWER PROGRESS REPORT

Atomic Radiation for Rocket Testing

by Alfred Cohen

Assistant Project Engineer in the Instrumentation Section of the RMI Test Department, Mr. Cohen is investigating new concepts for acquiring, reducing and evaluating test data. After graduating in mechanical engineering from City College of New York, he worked as a civilian test engineer for the Navy. Mr. Cohen came to Reaction Motors in 1954 as a Test Department Instrumentation Engineer.

Although the rocket engine in theory is an extremely simple powerplant, its development is a highly critical art. Successful operation of an engine depends upon the solution of many unique problems and the accurate measurement of unusual variables. One of the problems we encountered at RMI was the measurement of the corrosive effects of a new high energy rocket propellant, a problem we solved through the use of atomic radiation.

In determining the corrosive effects of propellants, it is essential that the sensing element employed does not come into direct contact with the propellant being tested. The propellant would rapidly damage or destroy most measuring equipment. In addition, the tolerance of the tests does not permit additional contamination from other foreign bodies.

We approached the problem on the basis that the density variation of the propellant could be the measure of its degree of corrosion upon the component materials with which it had been in contact . . . and the denser the material being tested, the less radiation would pass through it. We decided, therefore, to use the penetrating power of radiation as the tool to measure density variation.

To conduct the tests, a radioactive source and a detector for radiation were located so that the propellant being measured lay in a container between the two. The radioactive source emits gamma rays which penetrate through the propellant and its container. That part of the radiation that gets through the propellant and its container strikes the detector.

The detector contains a filling gas which is forcibly ionized when bombarded by atomic radiation. The energy of ionization is converted directly into electrical energy. Thus, an increase in the density of the propellant reduces the radiation field intensity at the detector, and results in a decreased generated signal.

However, accurate measurement of this energy is difficult because the generated signal is very low (in the magnitude of 1×10^{-13} amperes). To overcome this, an instrumentation system was specially developed to transmit, amplify and record this data.

The signal is transmitted to the amplifier by a special shielded cable that eliminates the effects of noise and other disturbances. Data is recorded by a Null system of measurement, using a ten-inch strip chart recorder. The recorder is calibrated to give full deflection for a density change equivalent to one tenth of a pound per cubic foot.

As a result of the data acquired by this test program, the research scientists have been able to improve the propellants to a point where they are both safe and highy desirable for use as rocket fuels.

This project is typical of one of the ways in which RMI Test Department supports the applied research, development and production projects associated with advanced rocket powerplants. All projects pass through this department, from the evaluation of components and fuels to the static "hot testing" of the entire engine system for an aircraft or missile before delivery.

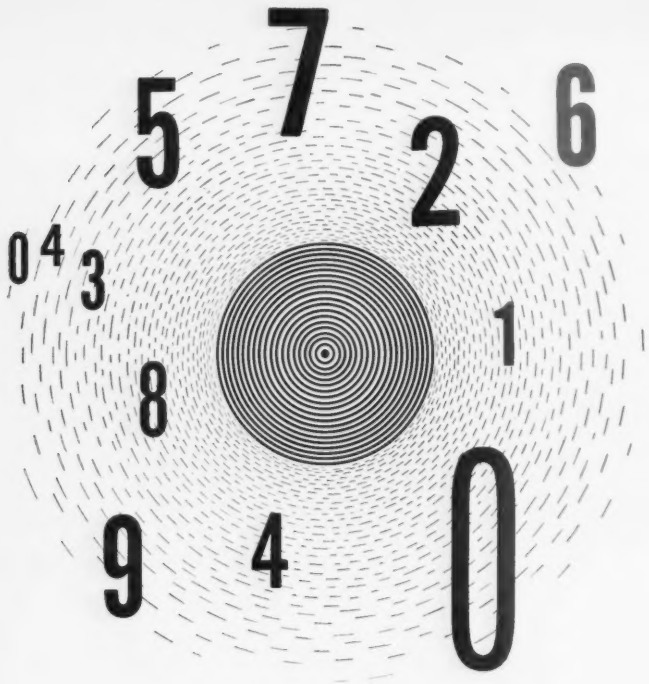
The Test Department is staffed by a team of specialists highly qualified in mechanics, electronics, chemistry, and instrumentation. This team is constantly working to provide the most accurate possible test results and also to develop new equipment and methods that will allow for even more accurate information in the future. And—because this team is constantly expanding—we are always anxious to talk with top-rated engineers and technicians who are interested in test work.

4986

If you desire one or more reprints of Mr. Cohen's article, or would like to receive further information about employment at RMI, write to our Information Services Coordinator. Reaction Motors, Inc., 22 Ford Road, Denville, N. J.

Power for Progress

RMI



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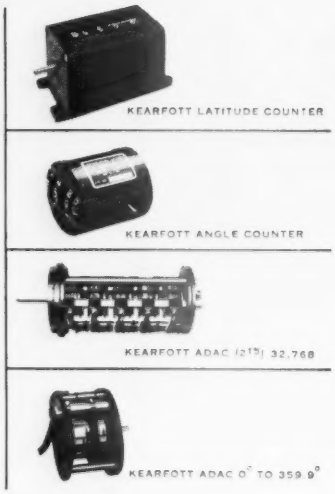

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North Carolina State College

L. M. Epps spoke on "The Importance of Weight Engineering in Aviation" at the April 1 meeting of the Branch which was joined by its ASME counterpart. Mr. Epps is Assistant to the Chief Technical Engineer at Grumman Aircraft Engineering Corporation.

He supplemented his talk with cartoon-type slides outlining the basic importance of weight analysis in design and performance of modern aircraft.

During the business part of the meeting, plans were discussed for participation in the Regional Student Conference.

JESSE HARRELL
Corresponding Secretary

Northrop Aeronautical Institute

New officers introduced at the February 16 dinner meeting were Chairman Robert Parker, Vice-Chairman James Fogarty, Treasurer Rodney Hutchinson, Recording Secretary Ernest Beechman, and Corresponding Secretary Norman Sakamoto.

Elwyn Angle of Systems Laboratories, Inc., spoke on "The Problems of Manned Space Travel." In his talk. Mr. Angle simulated a trip to the moon.

The problems of leaving earth seem insurmountable, but even more difficult is the problem of leaving the moon, he said. Transit time to the moon would be about $3^1/_2$ days, with 2 days to orbit the moon and another $3^1/_2$ to return to earth.

The big problem is landing on earth. He estimated it might take as long as a month to decelerate in elliptical orbits around the earth before landing. The number of orbits to be made would vary. One advantage in this type of deceleration is reduced fuel consumption.

Mr. Angle said current navigational instruments are inadequate for such a trip. Space travel demands an accuracy of one part in one million, compared to current flight demands of one part in one thousand.

In spite of these difficulties, Mr. Angle said space travel will be a reality in 15 years.

NORMAN S. SAKAMOTO, *Secretary*

The Pennsylvania State University

"Transitional Aircraft" was discussed by Joseph M. Zabinsky, Project Aerodynamicist, Bell Aircraft Company, at the March 7 meeting.

Mr. Zabinsky explained VTO aircraft, denoting the difference between tail-sitter and thrust-rotator methods of stabilization. Factors considered in design of VTO aircraft were explained with slides. He also showed movies of Bell's experimental VTO aircraft. He said this model, using a Schweizer glider fuselage and Cessna wings, was built to investigate direct thrust vertical take-off.

Jerry C. Dunlap was elected to fill the vacancy of the Secretary-Treasurer's office.

JERRY C. DUNLAP, *Secretary*

Purdue University

Alan Morse, Chief, Aircraft Division, CAA Technical Development Center,

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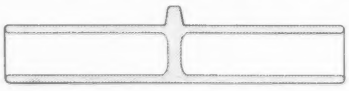
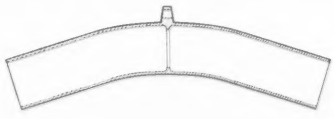
How would you produce this relatively simple component? Actually, it's not simple but Cameron had the cure. This actuator for the horizontal stabilizer of the North American F-100 Super Sabre is a cylinder with a thin solid center section and one central protrusion. For-



merly it was a weldment – two sections of tube stock with a small forging in the center – right here is where the headache developed because a cold bending operation was required. Welds parted, rejects were too high. The Cameron split-die forging process changed all of this.



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Indianapolis, discussed the center's development and testing activities at the March 7 meeting.

He provided running comments with a movie covering parts of the test program. Fire extinguisher tests on turbojet nacelles, resistance to rupture in wing-mounted fuel tanks, and a Navy catapult hurling wing sections against a cement wall were depicted.

Capabilities of the Boeing 707 to withstand impact from hailstones and flying birds were demonstrated. A freshly killed chicken wrapped in a cloth bag was shot at 100 m.p.h. against the cabin section.

▶ Development of the turboprop engine for the Lockheed Electra was discussed by George Clingman of Allison Division, General Motors Corp., before 50 members and guests at the February 21 meeting.

The talk was supplemented with a film explaining basic principles of the turboprop power plant.

CHARLES D. GREGORY, *Secretary*

Rensselaer Polytechnic Institute

The Student Paper Competition, presided over by the Branch faculty adviser, was held March 21.

The competition was divided into undergraduate and graduate categories. Harald von Kenschitzki spoke on "An Alternate Method of Pneumatic Propulsion," Anthony Templin on "A Theoretical Analysis of a Light Aircraft as Compared to Flight Test Results," and Henry Krieger on "Some Characteristics of Transonic Flow by a Thin Airfoil."

In the graduate division, Robert Stewart discussed "Boundary-Layer Growth in Shock Tubes" and Willie Lick spoke on "Relaxation Phenomena in Shock Tunnels."

The judges, Professors Foa, Li, and Yen of the Aeronautical Engineering Department, selected Mr. Krieger and Mr. Lick as winners. (The Branch presented them with books as prizes.) Mr. Krieger also was given the IAS Scholastic Award.

▶ Peter Viemeister of Grumman Aircraft Engineering Corporation spoke on "Carrier Aircraft—From Idea to Reality" at the March 13 meeting.

Mr. Viemeister explained the means by which a specific type of plane evolves. Preconceived military specifications sometimes determine preliminary design which is submitted in a design competition. Sometimes the company tries to predict future needs of the military, designs an airplane on this basis, and submits it for military approval. Another method is to revise and change a basic design into a new airplane.

When a firm is awarded a contract it proceeds with a detailed design and mock-up, construction of a prototype, structural tests, and test flights. Necessary modifications are made, and the prototype is submitted for service evaluation before full-scale production begins.

Mr. Viemeister concluded his talk with a discussion of several Grumman aircraft and their development.

ROBERT E. KELLY
Secretary-Treasurer

San Diego State College

Willard Dittman spoke on the effect of rain erosion on aircraft radomes at supersonic speeds before a joint meeting of the Branch and its SAE counterpart at the March 12 meeting. Mr. Dittman is Chief, Thermodynamics Laboratory, Convair, A Division of General Dynamics Corporation.

He showed a film illustrating methods of testing for rain erosion. These included firing a material sample from a 20-mm. cannon through simulated rain, 57-mm. cannon firing, and rocket sled tests at Mach 2 speeds at Edwards Air Force Base.

JAMES R. FRAHM, *Secretary*

Stevens Institute of Technology

Members discussed field trips to Curtiss-Wright Corporation, Grumman Aircraft Engineering Corporation, and Republic Aviation Corporation at the March 27 meeting.

These trips were scheduled during April and May.

A suggested engineer's banquet in conjunction with other engineering societies on the campus was discussed.

▶ An election of new officers for the 1957–1958 term was held at the March 13 meeting. Officers elected were Chairman W. Gerken, Vice-Chairman T. Helmer, Treasurer F. Carr, Corresponding Secretary J. Roe, and Recording Secretary W. Aehlich.

A film, *Range Unlimited*, was shown. It dealt with problems of refueling modern aircraft for long-range flights. The probe and drogue system for aerial refueling was cited as the most efficient and practical method.

This method makes use of tanker aircraft serving as in-flight refueling stations. The tanker trails a long tube called the drogue. When a short projection (probe) makes contact with the drogue, an automatic coupling device secures a continuous pipe line between the two aircraft.

Aerial refueling permits a bomber to reach any spot on the earth and return to base without landing.

GERARD FRIDSMA, *Secretary*
JAMES E. ROE
Corresponding Secretary

Syracuse University

A representative from North American Aviation, Inc., spoke on preliminary design and aerodynamic configuration at the March 12 meeting.

He covered history of airplane design, need for interceptor speed, collection of aerodynamic wing configuration, effect of sweptback wing at supersonic speeds, and thickness ratio on unit wing weight.

After a question and answer session, a film on use of rocket sleds in flutter testing was shown.

HARRY J. KIT, *Secretary*

Tri-State College

J. Youngman, Aerodynamicist, North American Aviation, Inc., spoke on "Longitudinal Stability and Control System" before 75 members and guests at the March 21 meeting.

Mr. Youngman explained problems encountered in investigations of stability and control system functions. He explained the longitudinal control system, static and accelerated longitudinal stability, longitudinal control system kinematics, longitudinal control fuel systems, stabilizer-elevator gearing, and pilot-induced oscillation. He said a balanced control system is important in preventing undue vibration.

The talk was illustrated with a film, *The Application of Rocket Sled Techniques to Flutter Testing*, showing tests on full-size tail sections.

Gene Kiser was presented with an attendance certificate. Certificates were also presented to the following members for their service as officers of the Branch during the winter quarter: William Seidel, Eugene Prue, Norman Mellott, and Donald Scharf.

KAZUMI HAMADA, *Secretary*

University of Alabama

A film, *The Sky Is No Limit*, taken at Holloman Air Force Base, N.M., was seen by 34 members at the March 21 meeting.

Major components of the Aerobee guided missile were discussed, from nose section to the booster. Steps involved in preparing the missile for launching, including safety precautions, and the actual launching of the missile were seen.

Philip L. Smith, Supervisor of Aeronautical Engineering Weapons Systems Division, Robbins Air Force Base, spoke on "Optical Tooling" after the movie. He explained it as the process used by the Germans in the last war quickly to set up aircraft factories after they were destroyed. Through this method, various parts and components of a plane are turned out with very close tolerances without the use of a master jig.

A chief objection to use of a master jig is its weight and the possibility of destruction during wartime. Optical tooling, on the other hand, is completely replaceable and makes for quicker, cheaper, and more accurate tooling. He showed photos of the process and some of its applications.

▶ Edward Lindsay, a 1949 graduate, spoke on "Ballistic Missile Development" at the March 7 meeting.

He discussed development methods and requirements and explained differences between separable and inseparable missiles. Inertial guidance systems are used to navigate most missiles, he said.

Mr. Lindsay showed filmed launchings of La Crosse, Little John, Honest John, Corporal, and Nike missiles, and a documentary on the Redstone, largest member of the missile family.

▶ A film on rocket sled techniques for flutter testing was shown by Lloyd E. Hackman, Structural Engineer at North American Aviation's Columbus Division, at the February 22 meeting.

Some 40 students saw actual flutter reduced to one-thirtieth true speed by the camera. Failure of horizontal and vertical tail structure was seen during a test on two tail sections.

Mr. Hackman said the problem of

flutter has increased in importance in recent years. During a question and answer period after the film, he outlined duties of an engineer in the various departments at North American. Pictures of testing setups and a typical project report were passed among the audience.

▸ New officers for the spring semester were introduced at the February 7 meeting. They are Chairman Delbert O. Like, Vice-Chairman Jack Lee, Secretary Charles Wells, and Treasurer Gordon Johnson.

The new chairman stressed the importance of lower classmen attending meetings and asked for suggestions to increase attendance. He also announced that the Branch has been invited to visit wind-tunnel facilities at Tullahoma, Tenn.

The Branch faculty adviser discussed the field trip to Tullahoma and the advantages of being a member of the IAS. He closed by announcing that the wind tunnel in the Aeronautical Engineering Laboratory would be open for inspection.

▸ After the election of officers at the January 17 meeting, members of the Branch presented a token of appreciation to Faculty Adviser Edward W. Geller, who is leaving to pursue further studies at The Johns Hopkins University.

CHARLES WELLS, *Secretary*

University of Illinois

James T. Overbey spoke on "Military Operations Analysis, A Tool for Better Planning" at the March 28 meeting. Mr. Overbey is Chief, Military Operations Analysis, Weapon System Advance Design, North American Aviation, Inc., Columbus Division.

He discussed the thinking or reasoning which goes into the selection of a particular type of weapons system for a specific mission. He compared current systems with those in existence 20 or 30 years ago to illustrate the complexity of those now in use. He gave special attention to the difficult problem of choosing one system from among many whose overall value is seemingly equal.

After the talk the meeting was open for general discussion.

▸ A. C. Frazer of Northrop Aircraft, Inc., spoke on "Supersonic Inlet Design Techniques" at the February 27 meeting.

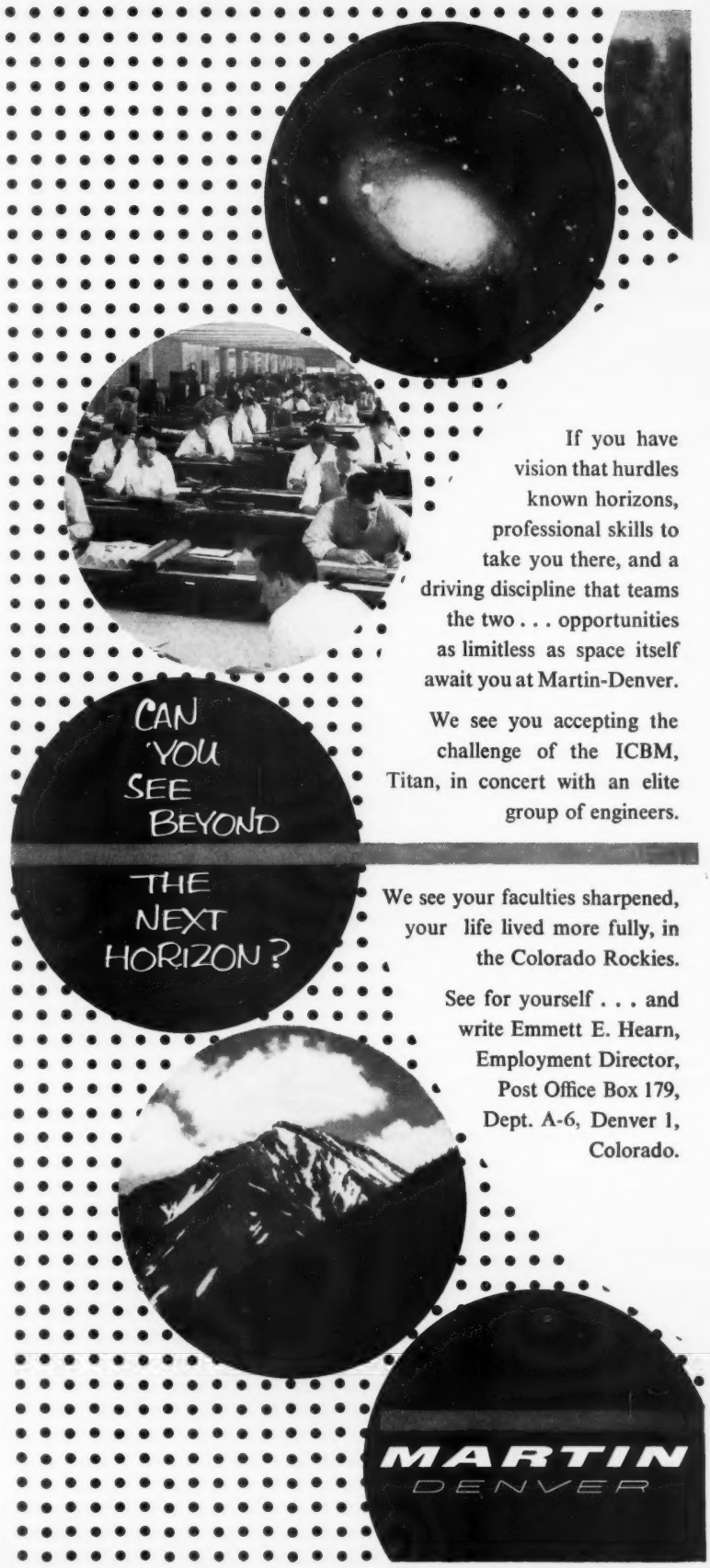
His talk centered on the derivation of working formulas needed in order to produce the desired inlet configurations. A group of slides showing schematic drawings of inlets and various graphs were used in conjunction with derived formulas to point out different aspects of the problem.

Harry H. Hilton, Branch Faculty Adviser, explained how to obtain exhibitors for participation in the Engineering Open House. The Treasurer's report was given by Charles Darling.

JERRY L. HARPER, *Secretary*

University of Kentucky

Roy Baldwin and William Cox, undergraduates in Mechanical Engineering, presented the papers they plan to enter in the Regional Student Paper Competition at the March 28 meeting.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Mr. Baldwin's paper was "Compartmented Fuel Tanks"; Mr. Cox's paper was "The Performance Test of the University of Kentucky Model 101 Continuous Disreefers." Members commented on the two papers and suggested improvements that might be made.

▶ Professor M. K. Marshall of the Mechanical Engineering Faculty spoke on "Some Aspects of Multistage Parachute Systems" at the February 28 meeting.

He explained the need for a parachute that will permit personnel to bail out at high-speed, high-altitude conditions. He said the use of an initial small parachute would permit a man to withstand deceleration and yet reach a safe altitude before freezing to death. An initial parachute would provide descent stability. It would be released automatically when the final parachute opened.

A. L. WITTWER, *Secretary*

University of Maryland

New officers elected at the April 4 meeting were Chairman George Sale, Vice-Chairman Gail Wisser, Secretary Robert Spenser, and Treasurer Murdo Smith.

W. E. Simon spoke on "Aerodynamic Heating" after elections. Mr. Simon is Group Engineer, Aeronautical Development, North American Aviation, Inc., Columbus Division

He examined and explained several approaches to the temperature question. Possible methods for reducing skin temperatures are (1) injection of fluid into the boundary layer, (2) radiation by control of surface conditions, (3) thermal lag effect by insulation, and (4) use of high-temperature materials to provide adequate strength.

A film, *The Application of Rocket Sled Techniques to Flutter Testing*, was seen by the 25 members present.

▶ George Towle spoke on "Jet Noise—Its Causes and Cures" at the March 7 meeting. Mr. Towle is Head, Acoustics Group, United Aircraft Corporation, Research Division.

He explained some of the problems involved in reducing jet noise created by turbulence in the jet stream. Data collected from model studies were used to develop a successful ground suppressor which has prevented audible, lower frequencies from occurring by shifting them to a higher range.

The suppressor was not successful in flight because of too great a thrust loss. Mr. Towle said that jet noise can be cured only while the plane is on the ground but that research is still trying to devise a nozzle to get appreciable reduction of noise in flight.

GAIL D. WISSER, *Secretary*

University of Michigan

"Future Aircraft Power Plants—Factors in Choosing Size and Type" was discussed by John W. Connors at the February 26 meeting of the Branch and its ASME counterpart. Mr. Connors is Assistant Project Head, Gas Turbine Division, Pratt & Whitney Aircraft.

He traced the history of the modern gas turbine from the August 2, 1939, flight test of the German Me-178 through development of the first Anglo-American jets. He listed several types of power plant available including internal combustion, turboprop, ducted fan, turbojet, ram-jet, and the rocket. Slides were used to illustrate the talk.

Mr. Connors estimated that it took from 8 to 10 years and $50 million to develop a new engine for production. The problem of selecting power-plant configurations for high-speed aircraft applications was reviewed. He discussed general methods for determining desired power-plant characteristics and design and showed results of typical power-plant evaluation studies.

MICHAEL A. REYNOLDS, *Secretary*

U.S. Air Force Institute of Technology

Colonel Joseph J. Berkow spoke on "The Air Force Flight Test Center and the Flight Test Engineer" before 27 members and guests at the March 4 meeting. Colonel Berkow is Chief, Flight Test Engineering Division, Air Force Flight Test Center, Edwards AFB.

He described the purpose and operations of the flight-test program and listed opportunities and advantages in flight-test engineering duties at Edwards AFB.

Colonel Berkow supplemented his talk with a classified film, *The Edwards Flight Test Center*. Later he answered specific questions about engineering assignments at the base put to him by members.

1ST LT. A. A. JANCAUSKAS, USAF
Secretary

U.S. Naval Postgraduate School

"Recent Developments of Naval Airplanes and Equipment at Douglas El Segundo" was discussed by Angus Jacks at a classified meeting on March 27. Mr. Jacks is a member of Douglas Aircraft Company, Engineering Department, Design Studies Department.

Some 50 members and guests heard Mr. Jack's talk which was augmented by slides and two short films.

Chairman Lt. John C. McCoy, USN, presided.

GEORGE E. JESSEN
Corresponding Secretary

MEMBERS ELECTED

The following applicants for membership or applicants for change of previous grades have been admitted since the publication of the list in the last issue of the Review.

Elected to Associate Fellow Grade

Drake, James F., M.S. in Ae.E., Dept. Mgr., Prelim. Design, Marquardt Aircraft Co.

Himmel, Seymour C., M.S. in M.E., Chief, Advanced Proj. Branch, NACA (Cleveland).

Holt, Maurice, Ph.D., Assoc. Prof., Appl. Math., Brown Univ.

McHugh, James G., B.S. in M.E., Aero. Research Engr., Dept. of the Army (Ft. Eustis).

Sandoz, Paul L., B.S. in M.E., Chief—Struct. Staff, Boeing Airplane Co. (Wichita).

Semler, Donald G., B.S. in Ae.E., Chief Engr., Stanley Aviation Corp.

Stern, Marvin, Ph.D. in Math., Tech. Asst. to V-P—Engrg., Convair Div. (San Diego), General Dynamics Corp.

Transferred to Associate Fellow Grade

Edwards, Lawrence K., A.B., Head, Systems Integration Dept., Missile Systems Div., Lockheed Aircraft Corp. (Van Nuys).

Fleming, William A., B.S. in Ae.E., Asst. Chief, Propulsion Systems Div., NACA (Cleveland).

Flickinger, Don D., M.D., Brig. Gen., USAF; Comdr., European Office, ARDC (Brussels).

Gilruth, Robert R., B.S. in Ae.E., Asst. Dir., Langley Aeronautical Lab., NACA (Langley Field).

Liepman, Hans P., Ph.D., Assoc. Prof., Univ. of Michigan.

Martin, James S., B.S. in Ae.E., Asst. Chief Tech. Engr., Republic Aviation Corp.

Morris, Brooks T., A.B. in E., Exec. Engr., Power Plants, Marquardt Aircraft Co.

Rhoads, Waldon R., B.A. in Physics, Dir., Nuclear Lab., Lockheed Aircraft Corp. (Marietta).

Stafford, Alfred B., B.S. in E.E., Prof. of Mech. and Aero. Engrg., Univ. of Wyoming.

Sullivan, Thomas M., B.S. in Ae.E., West Coast Mgr., Fairchild Engine Div., Fairchild Engine & Airplane Co. (Hollywood).

Walkowicz, Teddy F., D.Sc., in Ae.E., Tech. Adviser, L. S. Rockefeller.

Elected to MEMBER Grade

Abaid, George N., B.S. in E.E., Electrical Engr., Republic Aviation Corp.

Blonsick, John S., Jr., B. of Bus. Admin., Struct. Engr., North American Aviation, Inc. (Columbus).

Brown, Joseph M., Ph.D., in M.E., Pres., Structures, Inc.

Bryant, William B., Sc.D., Proj. Leader, Aerophysics Research Group, Massachusetts Institute of Technology.

Calhoun, Lawrence C., B.S., Flight Test Engr., Air Arm Div., Westinghouse Electric Corp. (Baltimore).

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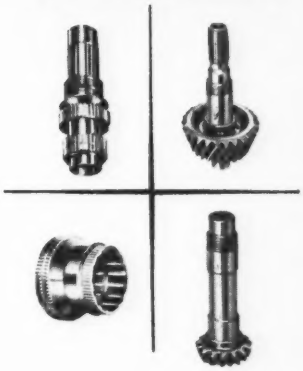

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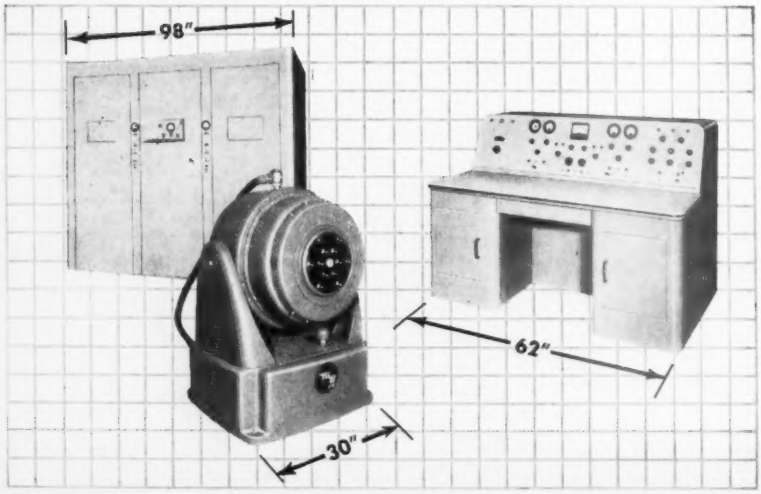

Cruz, Edward S., A.A., Group Engr., Lockheed Aircraft Corp. (Burbank).

Davis, Edward M., B.S. in M.E., Mgr., Patrol Dept., Prelim. Design, Lockheed Aircraft Corp. (Burbank).

Deal, Oliver E., Ph.D., Experimental Test Pilot, Hughes Aircraft Co.

Di Taranto, Rocco A., M.S., Sr. Engr., Radio Corp. of America.

Eckman, Fred A., M.E., Sr. Mech. Engr., Air Arm Div., Westinghouse Electric Corp. (Baltimore).

Emmick, William G., Chief Test Experimental Engr., Allison Div., General Motors Corp.

Fay, James A., Ph.D., Assoc. Prof., Massachusetts Institute of Technology.

Galow, Gordon T., Aerodynamics Engr., Fairchild Aircraft Div., Fairchild Engine & Airplane Corp.

Gruen, Kurtis, B.S. in M.E., Eastern Area Supvr., AGT Dept., Westinghouse Electric Corp. (Kansas City).

Henshaw, Douglas H., Ph.D., Aerodynamicist, The de Havilland Aircraft of Canada Ltd.

Jahn, Walter H., B.S., Aerodynamics Engr., Boeing Airplane Co.

Joste, Sten V., B.S. in E.E., Proj. Mgr., Swedish Air Service, Ltd.

Kirschbaum, Nathan, B.S. in Ae.E., Aerodynamics Engr., Grumman Aircraft Engineering Corp.

La Brenz, Howard J., Lt. Col., USAF; Chief, Weapons Systems Group for USAF at Boeing Airplane Co.

LeShane, Albert A., Jr., B.S. in Ae.E., Research Engr., United Aircraft Corp.

Levi, Oscar A., B.S. in Ae.E., Lead Flight Test Engr., Ryan Aeronautical Co.

Lowe, Raymond W., M.S. in Admin. Engrg., Asst. Proj. Engr., McDonnell Aircraft Corp.

Maidment, Clifford T., B.Sc., Sr. Aerodynamicist, Saunders-Roe, Ltd.

Mann, George L., A.B. in M.E., Thermodynamicist, National Rocket Corp.

Mathews, Robert L., B.S. in M.E., Chief Engr., General Sound Control, Inc.

Miller, Robert C., B.S. in M.E., Proj. Leader, Marquardt Aircraft Co.

Montgomery, J. Leonard, B.S. in E.E., Sr. Electronics Engr., Avco Manufacturing Co.

Noon, Alonzo W., B.S. in M.E., Sr. Mech. Engr., Stanford Research Institute.

Oliver, Henry, M.S. in Appl. Mech., System Analysis Engr., Sperry Gyroscope Co. Div., Sperry Rand Corp.

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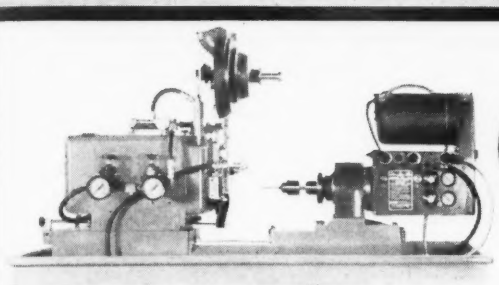
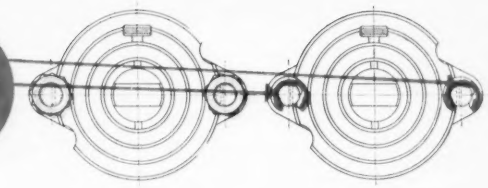
Waldes Truarc Retaining Rings Eliminate Machining and Parts—Cut Assembly Time on Drill and Tapper



Beco Model 410 Drill and Tapper

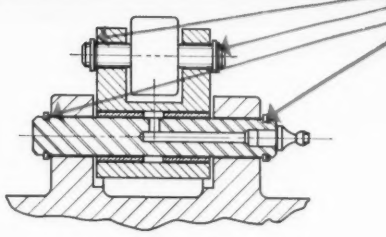
The Batchelder Engineering Co., Inc., Springfield, Vermont uses 4 different sizes of 2 different type Waldes Truarc rings in their new BECO Model 410 Automatic Drill and Tapper. Truarc rings speed assembly, reduce machining, improve design.



ALTERNATE DESIGN TRUARC DESIGN

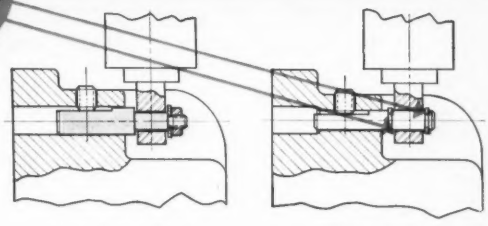
Clamp Cylinder Rod Stop Assembly

Truarc "E" Rings (Series 5133) replace stop nuts in the Clamp Cylinder assembly. They eliminate need for threading 2 rods ...the danger of cross-threading nuts...and costly rejects. Truarc Rings cut assembly time and cost.



Bell Crank Pivot Assembly

Truarc Rings (Series 5100) in Bell Crank Pivot assembly permit grease hole not possible with cotter pin fastener. Use of nuts would have increased machining and assembly costs considerably.



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LEAR

DATELINE world

PROFESSIONAL NOTES AND REPORTS

Engineering and Scientific Briefs from Correspondents Around the Globe

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jected to an additional longitudinal tensile load which, together with the internal pressure, produced a brittle fracture. This is in agreement with Fig. 2 of the work cited.

A question arises: Can the above formulas, which are derived for the elastic range, be applied at the moment of fracture? Limited experiments have shown that, at least in the case of pressure vessels, the type of fracture may be predicted by these formulas with good accuracy. The reason is that, in the case of pressure vessels, the deformations are similar in both the elastic and plastic ranges—i.e., there is no necking. A more accurate relationship is a matter of future research and of the theory of plasticity. For example, we might take into consideration strain hardening. In this case the straight lines representing shearing strength would become curves.

If a material of a cylindrical pressure vessel under stress satisfies the inequality $\tau_{max}/\sigma_{max} > t/s$, the vessel breaks in shear along a generator as shown in Fig. 1. That the fracture is in shear is indicated by the edge of the fractured plate which is under an angle of about 45° to the surface of the shell. This fracture does not usually propagate to the ends of the vessel because the ends of the cylindrical shell are reinforced by the heads. The bulging of the shell "a" which occurs, usually in the middle, produces considerable additional longitudinal stresses, and the shell cracks at the points "c" in circumferential direction. As soon as this happens, the further propagation of the cracks "b" does not require much energy. These are the tear cracks opportunely considered by Topping. They are studied in the technology of rubber and plastics and should be used in testing of metals since such tests can provide useful comparative data for the selection of materials to be used for thin-walled tanks. Because of stress concentration at the bottom of the crack, the radius of which is of atomic order, and because the resisting area is very small, it takes a very small force to propagate this type of crack. It is interesting to note that there are two distinct cases: If the acting forces are in the plane of the plate [Fig. 1(a)], the fracture is cohesive separation by the normal stress; on the other hand, if the acting forces are not on the plane of the plate [Fig. 1(b)], the fracture is of shear type (under 45°) because in this case there is a rapidly changing bending moment. This difference may be demonstrated even by tearing apart a sheet of paper.

Topping correctly considers the distortion energy theory as the best suitable theory for ductile metals. But the word "ductile" has no engineering meaning unless the state of stress is indicated. A metal which is ductile in tension may very well be brittle under combined stress, or metals which are brittle in tension may be ductile in torsion or compression. Where, then, is the boundary? The theory of distortion energy does not answer this question. Nor does it answer the question what will happen if the differences between the principal stresses remain small but their absolute values increase indefinitely? This is the reason why this theory is not reliable and cannot be reliable—because of the obvious fact that the knowledge of the behavior of a metal under uniaxial force is not sufficient to predict what will happen under a more complicated state of stresses. The only fruitful approach will be the one which is based on the fundamental nature of the strength of metals. Theoretical metallurgy gives us this basis: It recognizes only two ways in which metals resist to the acting forces—resistance to dislocation (slip) and resistance to cohesive separation. And the theory of strength of materials also recognizes two kinds of stresses—tangential and normal. Therefore, a true theory should be able to find which one of the two resistances will be overcome first by the corresponding stress and thus determine not only the type of fracture but the magnitude of the load which produces this fracture. This is the fundamental approach which cannot miss in the long run.

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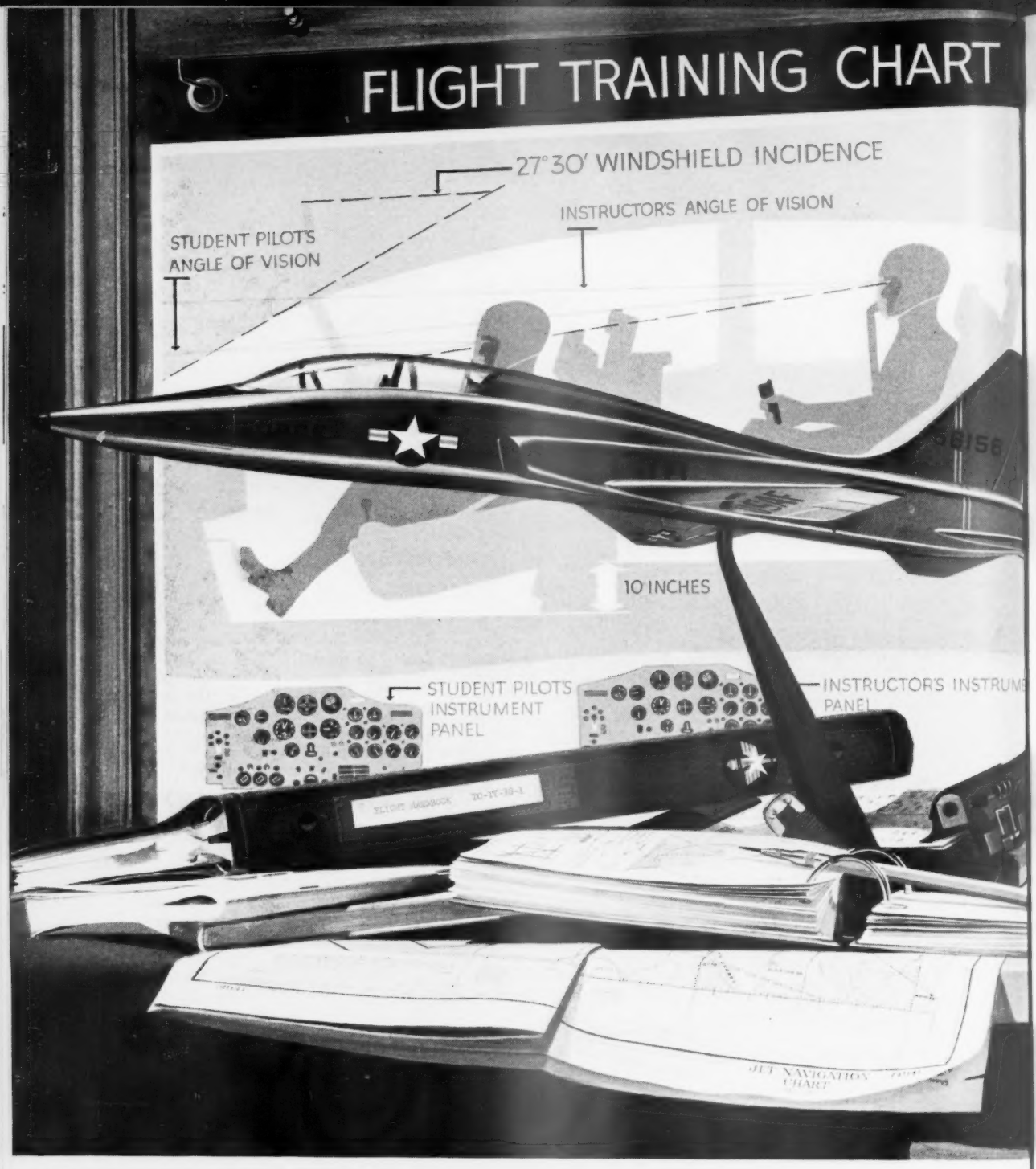

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Acoustics, Sound, & Noise

Aircraft Noise and Building Design. Adone C. Pietrasanta. *Noise Control*, Mar., 1957, pp. 11–18, 88. Methods for analyzing the effects of jet-aircraft noise on vocal communication and work performance in nearby office buildings.

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Boundary Layer

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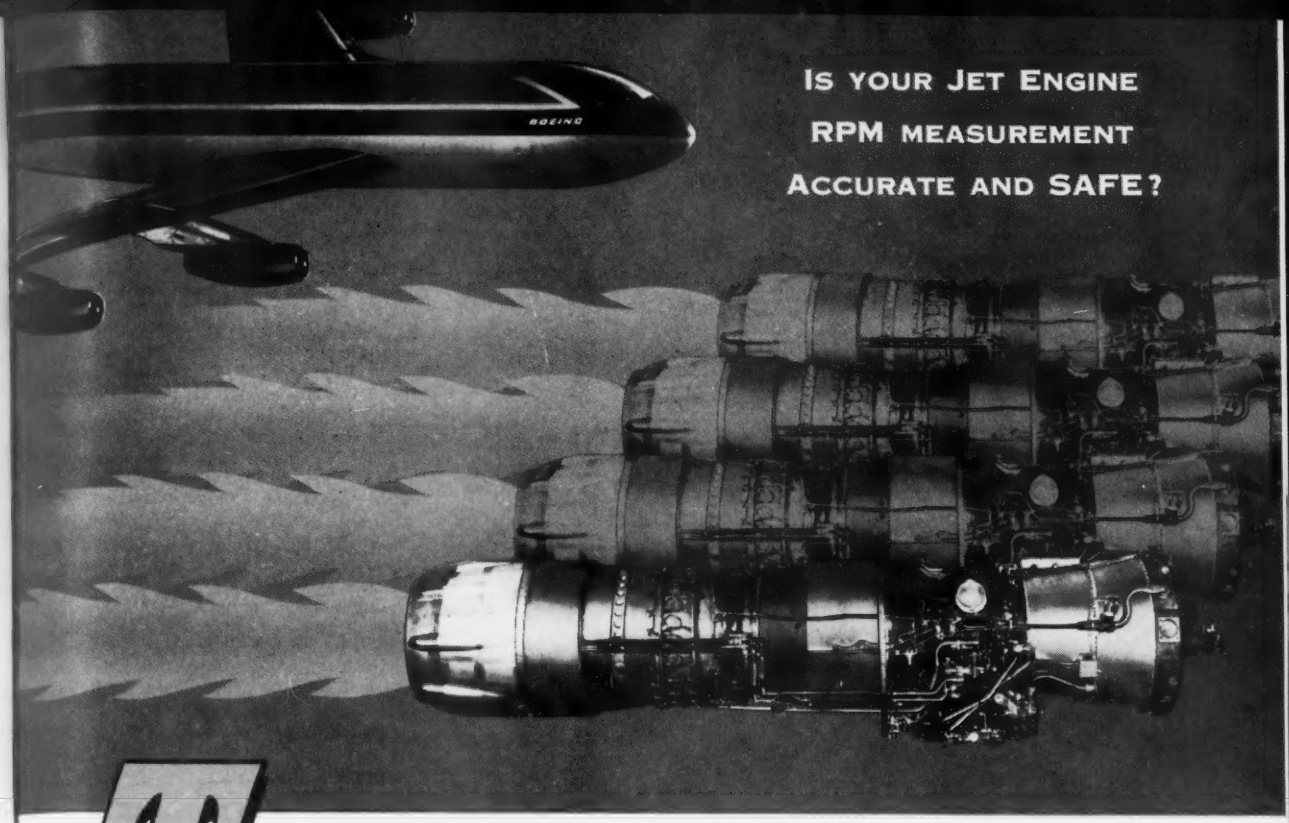

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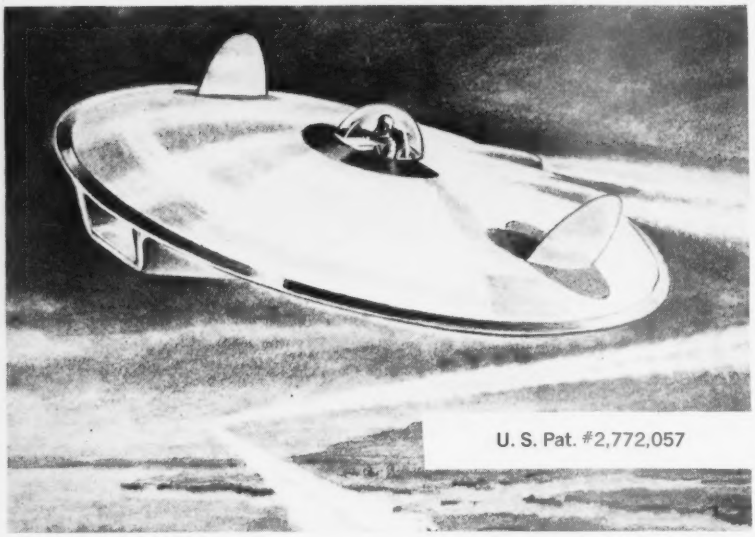

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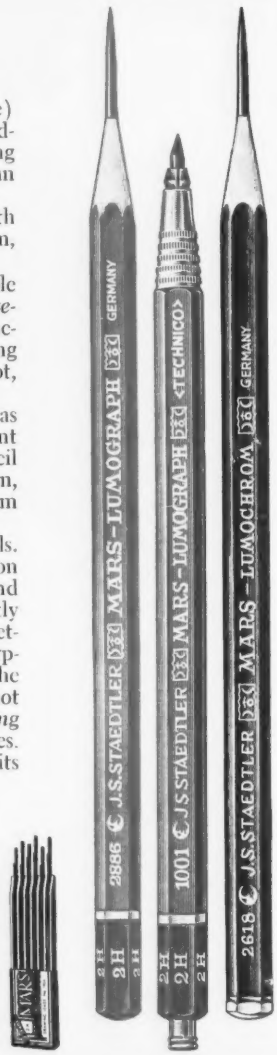

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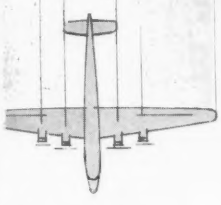

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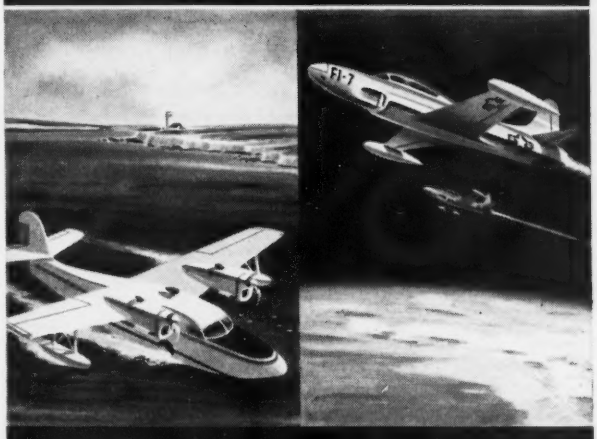

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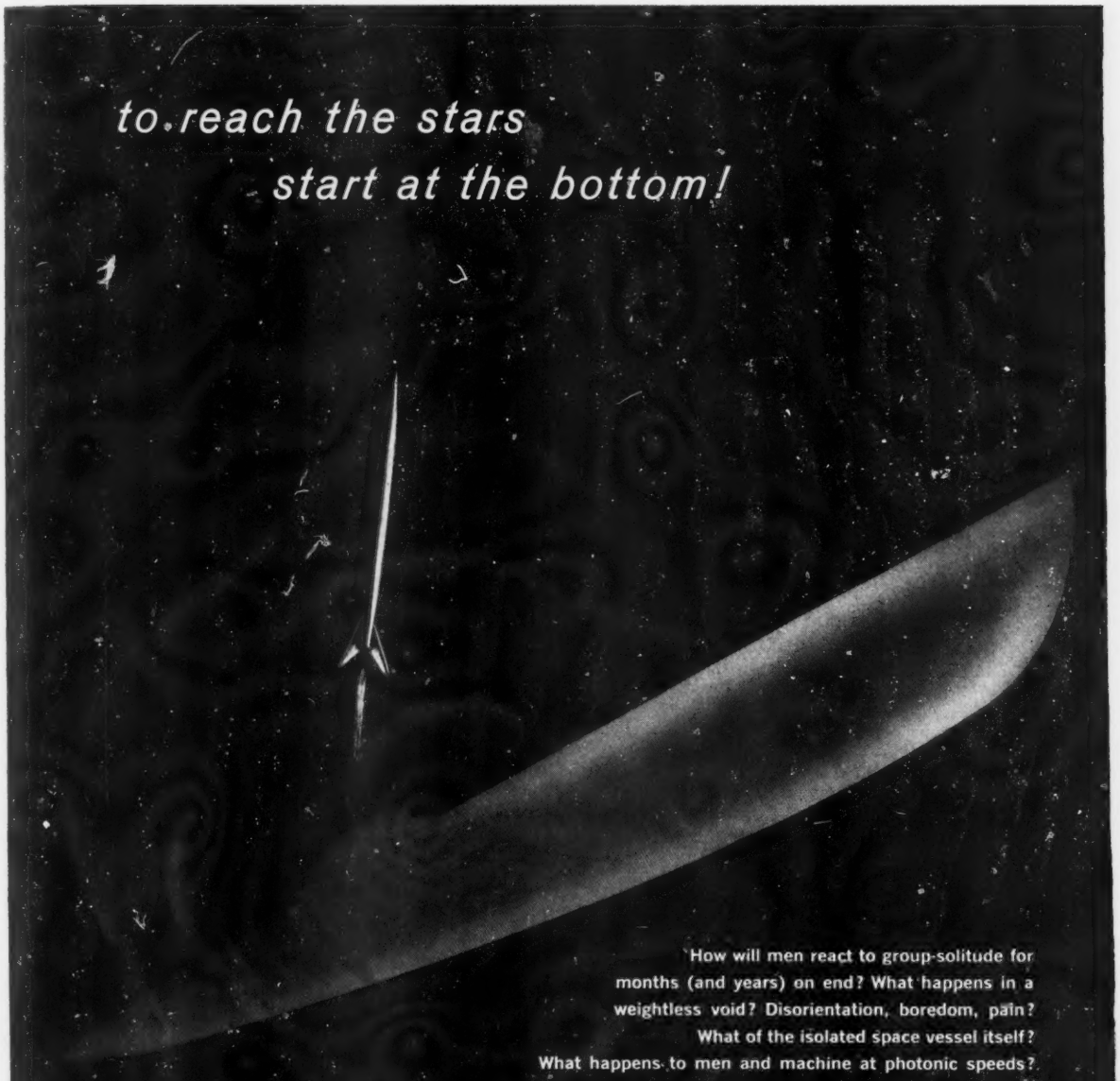

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Sizing Valves for Flashing Fluids. J. G. Ziegler. *ISA J.*, Mar., 1957, pp. 92–95. Graphical methods for choosing valve sizes to accommodate fluids which change

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density nonlinearly as they pass through the valve.

Transient Response of Hydraulic Actuators. E. Mucha. *Prod. Eng.*, Apr., 1957, pp. 175–177. Derivation of formulas for a conventional hydraulic actuator and for simple geometry (the ram moves in a straight line) for the following conditions: zero inertia and zero external load, zero inertia and constant external load, and inertia and constant or variable external loads.

Flight Operating Problems

Safe Takeoff in Multi-Engine Planes. III. Harley D. Kysor. *Av. Age.*, Apr., 1957, pp. 206–211 ff.

The "Black Hole." Arthur E. Jenks. *Skyways*, Apr., 1957, pp. 11, 34, 35 ff. Discussion of low-visibility approach and landing, and of the design configuration of visual aids in relation to the human eye.

Where do we Stand on Automatic Landings. Arthur F. Lohman. *Av. Age*, Apr., 1957, pp. 200, 201–204 ff. Discussion of the difficulties involved in developing automatic landing systems.

Development of Operating and Flight Planning Techniques for the Vickers Viscount. R. H. Chadwick. *Shell Av. News*, Feb., 1957, pp. 14–19. Discussion of flight problems encountered by BEA over Europe and methods of solution.

The Effect on Weather Minima of Approach Speed, Cockpit Cut-Off Angle and Type of Approach Coupler for a Given Landing Success Rate and Level of Safety. E. S. Calvert and J. W. Sparke. *Gt. Brit., RAE TN El.*130, Jan., 1957. 22 pp. Flight tests to determine amounts of time actually consumed in correcting azimuth displacements of various magnitudes. Operational research methods and simulated tests are used to find the minimum visual stimulus which must exist if the pilot is to make approach and landing maneuvers with an acceptable level of safety.

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Solid and Gaseous Fuels—Industrial Applications of Analysis, Control, and Instrumentation. W. H. Ode. *Anal. Chem., Pt. 2*, Apr., 1957, pp. 657–669. 295 refs.

Fire-Resistant Hydraulic Fluids. I—Emulsion Types. A. S. Morrow, H. E. Sipple, and R. T. Holmes. *Appl. Hydraulics*, Apr., 1957, pp. 78, 80–82. Discussion of the properties of "snuffer"-type fluids, which consist of petroleum oil mixed with water and emulsifying agents.

A Fuel Problem as Seen by an Aircraft Designer. Giovanni Casiraghi. *Esso Air World*, Jan.-Feb., 1957, pp. 104–107. Discussion of fuel problems associated with the future development of aircraft propulsion.

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Hydrogen Peroxide Field Analyzer. J. G. Tschinkel and T. D. Cantrell. *Jet Propulsion*, Mar., 1957, pp. 290–292. Method to measure the concentration of hydrogen peroxide in an aqueous solution.

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Freezing of Supercooled Water-Droplets. II. K. Hama and K. Itoo. *Papers in Meteorology & Geophys.*, July, 1956, pp. 99–106. Investigation in which water droplets are frozen on a cooling brass plate to find the effects of artificial rainmaking.

Propeller De-Icing; Electro-Thermal Mats for Viscounts. *Flight*, Mar. 1, 1957, pp. 283, 284.

Odladzanie Samolotow za Pómocą Grzejników z Metalu Natryskanego. Zbigniew Kowalski. *Tech. Lotnicza*, Nov.-Dec., 1956, pp. 173–178. In Polish. Study of aircraft deicing by means of metal-spray electric heaters.

Elektroobogrevaemye Stekla. S. Dekalenkov. *Grazhdanskaia Aviatsiia*, Jan., 1957, pp. 18, 19. In Russian. Description of a heating installation for windshield deicing systems.

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Instruments

Elektronenmikroskopie für die Luftfahrtforschung. Ernst Brüche. *ZFW*, Feb., 1957, pp. 43–49. In German. Discussion of examples of aeronautical uses for the electronic microscope.

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Quelques Remarques sur la Graduation et le Calage des Altimètres. A. Rouaud. *France, SGACC, Bul. Liaison & Doc. No. 88*, 1957, pp. 35–41. In French. Discussion of the calibration and adjustment of altimeters.

Incidence Indication for Aircraft. *The Engr.*, Mar. 22, 1957, pp. 457–461. Development of an instrument based upon finding a point on an airfoil surface at which there is a single-valued relationship between incidence and local pressure.

The Accurate Calibration of Flow-Meters with Water. E. A. Spencer and A. T. J. Hayward. *Trans. Soc. Instr. Tech.*, Mar., 1957, pp. 1–10; Discussion, pp. 10–12. 16 refs. Discussion of the possible sources of error in two calibration systems, with special reference to the calibration of a volumetric tank which was originally used as an absolute standard. Tests on a 4-in. diameter Venturimeter are presented as an illustration of the accuracy attainable with the pilot system.

The Gyroscope: A Proved Instrument Takes on New Significance. P. H. Wilson and L. T. Seaman. *G-E Rev.*, Mar., 1957, pp. 44–49. Discussion of the physical principles of gyroscope operation, and applications of the gyro to direction instruments, navigation, and guided missiles.

Essential Standardization. *The Aeroplane*, Feb., 22, 1957, pp. 261, 262. Recommendations for cockpit standardization for instruments giving speed, altitude, flight-path deviation, direction, and rate of climb.

Vibration Calibrator. D. L. Schacher. *Instruments & Automation*, Mar., 1957, pp. 470, 471. Description of an electronic micrometer for displacement measurement.

Automatic Control

El Automatismo en el Aire. Derek Harver. *Argentina Aérea*, Feb., 1957, pp. 9, 10. In Spanish. Discussion of automation in aircraft.

Issledovanie Dinamiki Releino-Impul'snykh Sistem Avtomaticheskogo Regulirovaniia. V. P. Kazakov. *Avtomatika i Telemekhanika*, Jan., 1957, pp. 34–46. In Russian. Development of methods for determining self-oscillations and transients of relay-pulse systems. These methods are based on frequency and time characteristics of continuous parts of the system.

Ob Odnom Sposobe Opredeleniia Zhelaemykh Logarifmicheskikh Chastotnykh Kharakteristik. P. S. Matveev. *Avtomatika i Telemekhanika*, Jan., 1957, pp. 71–77. In Russian. Development of a method for determining desired logarithmic frequency responses, with examples of practical application.

O Skol'ziashchem Rezhime Releinykh Sistem Avtomaticheskogo Regulirovaniia. Iu. I. Neimark. *Avtomatika i Telemekhanika*, Jan., 1957, pp. 27–33. In Russian. Study of the sliding process in control relay systems.

(*Continued on page 150*)

MISSILE SYSTEMS FLIGHT DYNAMICS

Weapon systems management activities at Lockheed's Palo Alto, Sunnyvale and Van Nuys organizations demand accomplishment of a high order in flight dynamics areas such as: Analysis of missile dynamic motion and establishment of stability and control system criteria for trajectories with 3 or more degrees of freedom; development of techniques for the analysis and interpretation of flight dynamics test data at hypersonic speeds; study of special dynamics problems arising during preliminary design and development of missile systems. Inquiries are invited. Please address the Research and Development Staff, Sunnyvale 21, California.

Left to right: S. S. Edwards, flight dynamics; B. W. Marsh, aerodynamics; M. Tucker, Aerothermodynamics Department manager; and R. L. Nelson, project aerodynamics, discuss reentry dynamics.

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ACOUSTICS, SOUND, & NOISE

FULL-SCALE INVESTIGATION OF SEVERAL JET-ENGINE NOISE-REDUCTION NOZZLES. W. D. Coles and E. E. Callaghan. US, NACA TN 3974, Apr., 1957. 45 pp. 13 refs. Tests on devices which, in general, achieve the desired effect by means of the mixing interference of adjacent jets, i.e., by using multiple-slot nozzles. Several of the nozzles achieve reductions in sound power of about 5 db. (nearly 70%) with small thrust losses. The maximum sound-pressure level is reduced as much as 18 db. in particular frequency bands, and some of the nozzles show considerable spatial symmetry. Treatment includes a method for calculating the limiting frequency affected by such nozzles. Data appear to indicate that further reductions in sound power will not easily be achieved with nozzles using mixing interference to suppress noise.

SURVEY OF THE ACOUSTIC NEAR FIELD OF THREE NOZZLES AT A PRESSURE RATIO OF 30. H. R. Mull and John C. Erickson, Jr. US, NACA TN 3978, Apr., 1957. 32 pp. 12 refs. Measurements of three cold-air exhaust nozzles, two of which are convergent-divergent and the other simply convergent. The total acoustic power radiated by the jet stream is about the same for the convergent-divergent nozzles and appears to be in agreement with predictions based upon tests at subsonic velocities and the Lighthill parameter. The convergent nozzle creates more than the predicted noise power based on the Lighthill parameter.

AERODYNAMICS

Aerothermodynamics

EXPERIMENTAL STUDY OF THE STAGNATION TEMPERATURE IN A FREE MOLECULAR FLOW. F. M. Devienne. J. Aero. Sci., June, 1957, pp. 403-406, 412. ARDC-supported measurement of the temperature of a small, thermally insulated, flat plate for high-speed motion in a free molecular flow. The plate is oriented perpendicular to the direction of motion and fixed at the extremity of an arm revolving at high speed in a vacuum chamber. Results, which indicate that the temperature increase of the plate is a function of the speed of the plate, are compared with values calculated from the theory for free molecular flow, which gives the same temperature increase as a function of the molecular speed ratio, the total emissivity, and the thermal accomodation coefficients of the surface.

THE TEMPERATURE AND CONCENTRATION PROFILES IN A HYPERSONIC LAMINAR BOUNDARY LAYER WITH COMBUSTION, INJECTION, OR SUBLIMATION AT THE WALL. S. M. Scala and G. W. Sutton. G-E MOSD ATM 35, Feb. 4, 1957. 34 pp. Exact solutions for the boundary-layer equations of mass, momentum, and energy are presented in the form of velocity, enthalpy, and concentration profiles for the case of Prandtl and Lewis Numbers equal to unity, and for zero pressure gradient and stagnation-point flow. Calculations are made for normal blowing from the wall, vector blowing from the wall, and for wall motion with and without blowing.

SEMINAIRE D'AEROTHERMIQUE DE LA FACULTE DES SCIENCES DE PARIS. France, Min. de l'Air NT 63, 1957. 110 pp. 78 refs. SDIT, 2 Av. Porte-d'Issy, Paris 15, Frs. 1,200. In French. Contents: LE REFROIDISSEMENT DES PAROIS PAR INJECTION PARIETALE, Jean Berger. TRANSMISSION DE CHALEUR PAR LES METAUX LIQUIDES S'ECOULANT DANS DES TUBES A SECTION CIRCULAIRE, Marcel Robin. SUPERAERODYNAMIQUE. ECHANGES THERMIQUES D'UN CORPS EN MOUVEMENT DANS UN GAZ RAREFIE, Marcel Devienne. SUR QUELQUES APPLICATIONS DE LA THEORIE DE LA COUCHE LIMITE DE DIFFUSION, Adalbert Oudart. LA CONVECTION NATURELLE, EN REGIME PERMANENT, D'UNE SPHERE A PEINE CHAUDE, Pierre Vernotte. EMPLOI DE L'INTERFEROMETRIE POUR L'ANALYSE DE LA STRUCTURE FINE DES ECOULEMENTS, P. Guienne and F. Bouniol. SUR LES PROFILS DE VITESSE DANS LA COUCHE LIMITE EN FLUIDE COMPRESSIBLE,

Gérard Gontier. ETUDE DES TECHNIQUES D'EXPLORATION DE LA COUCHE LIMITE EN FLUIDE COMPRESSIBLE, Max Plan. Studies including: wall cooling by parietal injection; heat transfer of liquid metals in circular ducts; heat exchange of a body moving in a rarefied gas; application of the boundary-layer diffusion theory; natural convection of a slightly warm sphere in permanent regime; interferometry used in the analysis of flow structure; velocity profiles in the compressible-fluid boundary layer; and exploration techniques for the study of compressible boundary layer.

INTERACTION OF MOVING SHOCKS AND HOT LAYERS. Appendix A - DECAY OF STEADY INTERACTION EFFECTS OF UNLIMITED SUPERSONIC FLOW WITH HOT LAYER OF FINITE HEIGHT. Appendix B - DEFORMATION OF NORMAL SHOCK AT LARGE HEIGHTS AND INFLUENCE ON SHAPE OF THROUGHGOING LAYER BEHIND SHOCK. Appendix C - QUASI-STEADY FLOW STABILITY OF COUNTERFLOWING REVERSE JET MOVING UNDER HOT LAYER. R. V. Hess. US, NACA TN 4002, May, 1957. 65 pp. 18 refs. Analysis emphasizing the cases of large hot-layer temperatures and strong shock waves for which small-perturbation theories are not applicable. A variety of possible interactions are described, including the most extreme cases when the hot layer is forced to accumulate in a growing bubble-like region bound to the moving shock, and some of the cold air above the layer moves around the bubble and interposes a high-speed forward-moving cold jet between the wall and the bubble. For some cases, especially with oblique shock, this reverse jet may not form. Mixing eventually limits the size of the bubble, whose characteristics then more nearly resemble those of the more familiar separation bubbles. The effects of viscosity at the wall remain essentially different, however, since the shock is moving relative to the wall.

APPROXIMATE LAMINAR SKIN FRICTION IN COMPRESSIBLE FLOWS WITH FAVORABLE PRESSURE GRADIENTS. E. S. Levinsky. Trend in Eng., Apr., 1957, pp. 13-19, 22. 13 refs. Method of estimating the laminar skin friction on two-dimensional bodies. Rott's modified Illingworth-Stewartson transformation, which is valid for any Prandtl Number, is used in the analysis, and calculations are made for both airfoils and flat plates. Results indicate that, to predict the variation of skin friction with Mach Number and temperature, a viscosity law (C) of the type employed by Chapman and Rubesin must be used. It is also shown that laminar skin friction is very nearly proportional to $\sqrt{C}$ for zero and favorable pressure gradients, and that the effect of Prandtl Number on laminar skin friction is negligible.

SKIN HEATING DURING RE-ENTRY OF SATELLITE VEHICLES TO THE ATMOSPHERE. T. R. F. Nonweiler. J. Brit. Interplanetary Soc., Jan.–Mar., 1957, pp. 10--21. Analysis of wing design and flight altitude emphasizing that the highest temperature reached at the leading edge of the wing of an aircraft in level flight at speeds of the order of the circling velocity need be no more than 1,000°C. Formulas and charts are presented for predicting the actual skin-temperatures close to the nose, for a wedge-shaped wing, in terms of skin thickness and conductivity.

SKIN TEMPERATURES AND HEAT TRANSFER OVER WEDGE WINGS AT EXTREME SPEEDS. Appendix I - CONDITIONS IN BOUNDARY LAYER OF AN INCLINED PLANE SURFACE PRODUCING AN INTENSE ATTACHED SHOCKWAVE. Appendix II - CONDITIONS BEHIND AN INTENSE INCLINED SHOCKWAVE IN AIR. T. Nonweiler. Coll. of Aeronautics, Cranfield, Rep. 105, Aug., 1956. 33 pp. Formulas and charts permitting the prediction, in terms of skin thickness and conductivity, of the actual skin temperature close to the nose, for a wedge-shaped wing. A limit is established to the maximum temperature reached, close to the wing leading edge, in sustained flight at speeds comparable to those involved in the flight of a satelite vehicle. A method is found for determining this limit as well as the rate of heat transfer at extreme speeds. Measures are suggested for reducing the maximum skin temperature obtained by these means and numerical values are calculated, by way of illustration, of the temperature reached by an aircraft which has been designed to include these measures and is flying at the particular speed at which kinetic heating effects are most severe.

HEAT TRANSFER AND SKIN FRICTION OF YAWED INFINITE WINGS WITH LARGE SUCTION. Appendix A - EQUATIONS OF MOTION AND THEIR TRANSFORMATIONS (COMPRESSIBLE CASE). Appendix B, C - INCOMPRESSIBLE EQUATIONS. H. G. Lew and J. B. Fanucci. Penn. State U. Dept. Aero. Eng. TR 8 (AFOSR TN 57-63) [AD 120404], Nov., 1956. 40 pp. Analysis of flows with such free-stream velocities as are required for similarity. Formal solutions for boundary-layer properties are presented in the form of asymptotic series. Simple relations are then determined for the skin-friction coefficient and the heat-transfer variations for both the compressible and incompressible cases, and a modified Reynolds analogy for the compressible case is obtained. In the compressible case the skin-friction ratio varies linearly with the pressure gradient parameter (β), the sweep back factor (ω), and the heat transfer parameter (S_o). The heat transfer coefficient (h_t) is decreased considerably by increasing sweepback.

ON THE HEAT TRANSFER COEFFICIENTS OF CYLINDRICAL BODIES. II. T. Tsubouchi, S. Sato, and H. Usami. Tôhoku U., Rep. Inst. High Speed Mech., vol. 7, 1956, pp. 31-44. Experimental investigation to measure the heat losses from the end surfaces of a circular cylinder. These end surfaces are located horizontally upward and downward in the still air, and both heated and unheated cylindrical surfaces are considered. The boundary-layer temperature method is used in conjuction with the heat-quantity method, and the local and mean heat-transfer coefficients of each surface are evaluated from the test data and expressed by experimental formulas which show remarkable differences from the case of the horizontal plates.

A PHENOMENOLOGICAL THEORY OF THE FREE TURBULENT FLOW OF A NON-REACTING BINARY GAS MIXTURE. L. G. Napolitano. Polytech. Inst. Bklyn., Dept. Aero. Eng. & Appl. Mech., PIBAL Rep. 317 (AFOSR TN 57-39) [AD 115077], Dec., 1956. 46 pp. 12 refs. Derivation of the basic equations describing the free turbulent motion of a nonreacting binary gas mixture. Classical results of the kinetic theory of nonuniform gases are used and, upon extension of the Reynolds similarity concept, all conductive currents are neglected and the resulting equations are presented in curvilinear orthogonal coordinates. Turbulent transport fluxes, which are subsequently related to pertinent mean gradients through phenomenologically defined eddy coefficients, are defined and their analogy with the corresponding molecular conductive currents is discussed. For the first time, the eddy diffusion coefficient is defined and a turbulent Schmidt Number is introduced showing its dependence on the relative magnitude of mass concentration and velocity mixing lengths.

Boundary Layer

LAMINAR BOUNDARY LAYER ON A SPINNING CONE AT SMALL ANGLES OF ATTACK IN A SUPERSONIC FLOW. R. Sedney. J. Aero. Sci., June, 1957, pp. 430-436, 455. 14 refs. Analysis using the perturbation method to find the exact solution for the boundary-layer equations applicable for the case of a small angle of attack and small spin. The cone angle and the free-stream Mach Number are such that the nonviscous flow is conical. A Prandtl Number of unity and a linear viscosity-temperature relation are also assumed. For a slender cone the results are used to calculate the Magnus effects due to displacement thickness.

PREDICTION OF TRANSITION IN THE BOUNDARY LAYER ON AN AEROFOIL. L. F. Crabtree. Gt. Brit., RAE TN Aero. 2491, Jan., 1957. 10 pp. 12 refs. Establishment of an empirical criterion for the limit of existence of a laminar boundary layer in which the necessary parameters must be able to describe separation and instability, as well as being physically reasonable and simple to calculate. Two parameters fulfil these conditions, and a universal curve is constructed for boundary-layer Reynolds Number and plotted against a pressure gradient parameter at transition. An assessment of its accuracy in comparison with previous methods is given.

ON TRANSITION FROM LAMINAR TO TURBULENT FLOW. Francis R. Hama, James D. Long, and John C. Hegarty. J. Appl. Phys., Apr., 1957, 388-394. OSR-supported investigation making use of water-tank observations of the flow phenomena associated with boundary-layer transition. It is shown that a two-dimensional discrete vortex line, which is considered to be the result of an amplified perturbation wave, has a strong tendency in shear flows to form three-dimensional vortex loops with a marked transverse wavelength. The formation and development of the vortex loop is found to be the essential feature preceding the creation of a turbulent spot which takes place near the top of the vortex loop and near the outer edge of the boundary layer.

STABILITY DIAGRAMS FOR LAMINAR BOUNDARY LAYER FLOW. Appendix A - A METHOD OF INTEGRATION USING ANALYTICAL CONTINUATION. R. Timman, J. A. Zaat, and Th. J. Burgerhout. Netherlands, NLL TN F.193, Oct. 10, 1956. 25 pp. Diagrams applicable for a one-parameter family of boundary-layer velocity profiles. The calculation method used starts from the asymptotic behavior of the inviscid differential equation of disturbance and makes use of only one solution in the complete domain of investigation.

I - THE EFFECT ON TRANSITION OF ISOLATED SURFACE EXCRESCENCES IN THE BOUNDARY LAYER. N. Gregory and W. S. Walker. II - BRIEF FLIGHT TESTS ON A VAMPIRE I AIRCRAFT TO DETERMINE THE EFFECT OF ISOLATED SURFACE PIMPLES ON TRANSITION. D. Johnson. Gt. Brit., ARC R&M 2779, 1956. 23 pp. 14 refs. BIS, New York, $1.17. I - Experimental investigation using photographs of some of the flow patterns visualized by smoke and china-clay techniques to determine the effect of isolated surface excrescences in a laminar boundary layer on the production of disturbances which may lead to turbulent flow. From measurements on a flat plate and two airfoils to find the critical heights of pimple which just give rise to spreading wedges of turbulent flow, a method is derived for approximating the protuberances permissible on laminar-flow surfaces at full-scale flight Reynolds Numbers. II - Two flight tests are made to show the effect of tiny paint pimples on the laminar boundary layer at a Reynolds Number (based on wing chord) of 25×10^6 near sea level.

Control Surfaces

LOW-SPEED TUNNEL TESTS OF SOME SPLIT FLAP ARRANGEMENTS ON A 48-DEG DELTA WING. I - THE DRAG OF BRAKE FLAPS ON A DELTA WING. II - THE EFFECTS OF FLOW RE-ATTACHMENT BEHIND SPLIT FLAPS ON A DELTA WING. J. F. Holford and J. W. Leathers. Gt. Brit., ARC R&M 2996, 1957. 30 pp. BIS, New York, $1.62. Investigation of the effects of solid and vented flaps at various positions on a delta wing. The first part deals with the drag of brake flaps; the second with the phenomena of flow re-attachment behind the flaps and its flap characteristics. It is shown that for small flap angle a type of flow exists which re-attaches to the wing surface behind the flap, causing negative flap lift coefficients and positive pitching moments. Transition to this type of flow depends on the ratio of the height of the flap trailing edge off the wing surface to its distance ahead of the wing trailing edge and also on the flap aspect ratio.

Fluid Mechanics & Aerodynamic Theory

PLANE COUETTE FLOW AT LOW MACH NUMBER ACCORDING TO THE KINETIC THEORY OF GASES. Hsun-Tiao Yang and Lester Lees. GALCIT

Hydrodynamics Lab. Rep. M-36, Feb. 1, 1957. 37 pp. 15 refs. Application of Grad's 13-moment approximation for solving the Maxwell-Boltzmann equation to the problem of the relative shearing motion between two infinite, parallel flat plates (plane Couette flow). In order to bring out the molecular effects as directly as possible, the problem is linearized by requiring that the Mach Number be small compared with unity and that the temperature difference between the two plates be small compared with ambient temperature. Examination of the drag data obtained by Kuhlthau, Chiang, and Bowyer and Talbot in their rotating-cylinder experiments at low densities shows that the variation of $1/C_DM$ with the parameter Re/M is predicted reasonably well by the present theory over a range of Mach Numbers from 0.15 to 1.40, in spite of the fact that the theory is supposed to hold only for low Mach Numbers.

RAYLEIGH'S PROBLEM AT LOW MACH NUMBER ACCORDING TO THE KINETIC THEORY OF GASES. Hsun-Tiao Yang and Lester Lees. J. Math. & Phys., Oct., 1956, pp. 195-235. 33 refs. Application of Grad's 13-moment method to Rayleigh's problem. The boundary conditions are restated for the case of a moving surface, and certain equivalent assumptions are retained. The differential equations and boundary conditions are linearized, and momentum and energy are uncoupled. Solutions obtained in this case should provide a basis for attacking Rayleigh's problem with arbitrary plate velocity, where the pressure, temperature, and velocity fields are interrelated.

A CORRELATION OF FREE-FLIGHT TRANSITION MEASUREMENTS ON VARIOUS BLUNT NOSE SHAPES BY USE OF THE MOMENTUM-THICKNESS REYNOLDS NUMBER. W. R. Witt, Jr., and J. Persh. (Aero. Range Symposium, Proc., Jan., 1957.) US, Army Bal. Res. Lab., Aberdeen, Rep. 1005, Pt. I, Mar., 1957, pp. 23-43. USAF-supported investigation of transition in boundary-layer flow by firing a systematic series of blunt-nose shapes into a pressurized ballistic range. The nose shapes are fired near a Mach Number of 3 and the Reynolds Number per foot is varied by changing the pressure (density in the firing range). The transition is determined directly from shadowgraph plates and the Reynolds Number, based on momentum thickness at the observed transition location, is calculated using the Cohen-Reshotko method. Results indicate that transition occurs at values of momentum thickness which are of the same order of magnitude as the values of minimum critical Reynolds Number usually associated with incompressible flow.

ON MAGNUS EFFECTS CAUSED BY THE BOUNDARY-LAYER DISPLACEMENT THICKNESS ON BODIES OF REVOLUTION AT SMALL ANGLES OF ATTACK. J. C. Martin. J. Aero. Sci., June, 1957, pp. 421-429. 10 refs. Analysis of the laminar boundary layer on a cylindrical portion of a slender body of revolution, to obtain a solution of the three-dimensional boundary-layer equation. The displacement thickness is found and used to calculate the Magnus force and center of pressure by means of slender-body theory. The Magnus effects caused by turbulent boundary layers under certain assumptions, and values from the resulting expression for the center of pressure, are compared with data obtained from range firing. The results show that the laminar boundary layer can cause Magnus effects of the proper sign and magnitude at small angles of yaw, even without separating ahead of the base.

A NOTE ON THE EFFECT OF HEAT TRANSFER ON PEAK PRESSURE RISE ASSOCIATED WITH SEPARATION OF TURBULENT BOUNDARY LAYER ON A BODY OF REVOLUTION (NACA RM-10) AT A MACH NUMBER OF 1.61. K. R. Czarnecki and A. R. Sinclair. US, NACA TN 3997, Apr., 1957. 13 pp. Experimental investigation using a technique which employs shock angles to determine the peak pressure rise for separation. Results indicate little or no effect of heat transfer on the shock angles associated with separation and, hence, on the peak pressure rise required to separate a turbulent boundary layer.

CHARACTERISTICS OF A 40° CONE FOR MEASURING MACH NUMBER, TOTAL PRESSURE, AND FLOW ANGLES AT SUPERSONIC SPEEDS. F. J. Centolanzi. US, NACA TN 3967, May, 1957. 36 pp. 10 refs. Experimental investigation on a cone having a total-pressure orifice at the apex and four equally spaced static-pressure orifices on the surface. Pressure measurements are taken at angles of pitch up to 26° at Mach Numbers of 1.72, 1.95, and 2.46 and for Reynolds Numbers of 3.12×10^6 and 5.41×10^6 per ft. Charts are presented which can be used in conjuction with the measured cone pressures to find the appropriate flow quantities.

THE FORCES EXPERIENCED BY TWO CIRCULAR CYLINDERS IN A UNIFORM FLOW AT SMALL REYNOLDS NUMBERS. Shinji Kuwabara. J. Phys. Soc. Japan, Mar., 1957, pp. 291-299. Calculation of the drag and lift coefficients for one of two parallel circular cylinders, using Imai's general method for solving Oseen's two-dimensional equations. It is shown that the general expressions for these coefficients become very simple when the two cylinders are placed symmetrically with respect to uniform flow. Numerical calculations are carried out in several cases for various parameters.

THEORETICAL AERODYNAMIC FORCES AND MOMENTS FOR A SLENDER BODY MOVING THROUGH THE FLOW FIELD OF A NEARBY SLENDER BODY. H. W. Woolard. Cornell Aero. Lab. Rep. GC 910C15, Oct., 1956. 25 pp. Derivation of appropriate approximate formulas based on slender-body theory, expressed in terms of the store shape and motions and in terms of the carrier-vehicle flow field in the vicinity of the store. Mutual interference is neglected. Applications to the pure translational motion of a body of revolution and to such a body with equal-span cruciform fins are presented. The steady-flow pressure coefficient is found for a slender store in the vicinity of a nonslender carrier vehicle.

EXPERIMENTS ON THE GROWTH OF VORTICES IN TURBULENT FLOW. Appendix - TURBULENCE MEASUREMENTS. I M. Titchener and A. J. Taylor-Russell. Gt. Brit., ARC CP 316, 1957. 17 pp. BIS, New York, $0.54. Measurements of the flow in turbulent line vortices along the center of a pipe to determine the growth of trailing vortices in the wake of an airplane. Results indicate that the rate of growth is small and of the same order as for a laminar line vortex.

Internal Flow

CIRCUMFERENTIAL INLET DISTORTIONS IN AXIAL FLOW TURBOMACHINERY. Fredric Ehrich. J. Aero. Sci., June, 1957, pp. 413-417. Actuator-disc type of analysis to determine the effect of a nonuniformity in the circumferential velocity profile entering an axial-flow stage of turbomachinery. Treatment is restricted to the study of incompressible, inviscid flow with the assumption of hub-tip ratios close to unity reducing the problem to two dimensions. Expressions are derived for the attenuation of the velocity distortion through the stage, the circumferential shift in the profile, and the fluctuation in load felt by the rotor blades passing through the nonuniform velocity field - all as a function of stage geometry. Results are given for compressor, turbine, and free-wheeling stages as a function of wheel speed, stage loading, and mean stagger angle.

A GRAPHICAL METHOD OF PREDICTING THE OFF DESIGN PERFORMANCE OF A COMPRESSOR STAGE. J. F. Louis and J. H. Horlock. Gt. Brit., ARC CP 320, 1957. 21 pp. BIS, New York, $0.63. Description of a procedure, based on Horlock's actuator disc theory, which involves the determination - repeated for different flow coefficients - of the static pressures at different radii which satisfy the radial condition far downstream of the following rotor row. By this means, the complete characteristics of the static pressure rise at different radii are obtained. The same method may be used to determine the flow through the stator, and then to the next stages. It may also be applied in the stalled region as long as recirculation does not appear at any section of the blades, and cascade data of sufficient accuracy are available.

FLOW INSTABILITY OF CENTRE-BODY DIFFUSERS AT SUPERSONIC SPEEDS. D. Beastall. Gt. Brit., ARC R&M 2933, 1956. 12 pp. BIS, New York, $0.63. Discussion of certain types of flow instability which manifest themselves as oscillations of the shock pattern ahead of the diffuser. Two types are distinguished: a violent oscillation which occurs when the flow through the diffuser is throttled below a certain value; a less severe oscillation which occurs when the vortex sheet from the intersection of the shock waves ahead of the diffuser or a separated boundary layer strikes the cowl. The explanations of the oscillations are substantiated by schlieren photographs of two- and three-dimensional model diffuser tests in a wind tunnel.

ON THE MUTUAL INTERFERENCE OF NEIGHBOURING TWO CASCADES COMPOSED OF HYDROFOIL OR AERO-FOIL PROFILES. S. Abe. Tôhoku U., Rep. Inst. High Speed Mech., vol. 7, 1956, pp. 1-14. Derivation of a theoretical method for determining the effect of mutual interference by replacing an impeller or guide vane with an exact cascade of hydrofoils or airfoils and by treating the effect of the other like a vortex sheet. A numerical calculation is performed for a particular cascade arrangement to determine, for each cascade, the magnitude of circulation caused by mutual interference. The present theory is compared to an earlier one dealing with the case where the two cascades are infinitely far apart.

NUMERICAL SOLUTION ON CHARACTERISTICS OF PROFILES WITH LARGE CAMBER IN CASCADE OF SMALL PITCH-CHORD RATIO. K. Seya. Tôhoku U., Rep. Inst. High Speed Mech., vol. 7, 1956, pp. 175-187. Derivation of a method of successive approximations for solving Laplace's finite-difference equation for the stream function of flow through a cascade. Numerical calculations are carried out to assess the accuracy of the method and to obtain the pressure distribution around a guide-vane profile of gas turbines.

AN EXPERIMENTAL ARRANGEMENT FOR THE MEASUREMENT OF THE PRESSURE DISTRIBUTION ON HIGH-SPEED ROTATING BLADE ROWS. K. Leist. (ASME Conf., Washington, Apr. 16--18, 1956.) Trans. ASME, Apr., 1957, pp. 617-626. Measurements on coaxial cylindrical sections to obtain information leading to the development of the three-dimensional theory of axial-flow turbomachines. The method described is shown to provide a complete representation of the pressure distribution which then may be photographed, and to offer, as well, an automatic check against leakage. Basic investigations are also made concerning the influence of different pitch ratios, and the results thereof are presented as examples illustrating the relative variations of the pressure distribution with blade pitch.

STABILITY OF LAMINAR FLOW IN CURVED CHANNELS. Chia-Shun Yih and W. M. Sangster. Philos. Mag., 8th Ser., Mar., 1957, pp. 305-310. Analysis to explain the occurrence of secondary flow in a viscous fluid flowing under a pressure gradient in a curved channel. It is shown that instability can occur even after the full establishment of the primary flow. Chandrasekhar's method is used in the analysis, and the relationship between the stability parameter and the wave number of the disturbance for neutral stability is obtained.

EXPLORATORY STUDY OF GROUND PROXIMITY EFFECTS ON THRUST OF ANNULAR AND CIRCULAR NOZZLES. U. H. von Glahn. US, NACA TN 3982, Apr., 1957. 48 pp. Experimental investigation, the results of which show that proximity of the ground to an annular nozzle will cause a thrust augmentation. The thrust for an annular nozzle compared to that for a circular nozzle of equal flow area will be on the order of 50% greater for a ratio of nozzle-to-ground distance/annular-

nozzle-base diameter of 0.2. The nozzle-to-ground distance at which thrust augmentation begins is a function of nozzle pressure ratio and the ratio of nozzle flow area to nozzle-base area, typical values being on the order of 1.2 to 1.6 times the nozzle-base diameter. With a circular nozzle the proximity of the ground will cause a decrease in thrust. A brief discussion is included on the significance of these studies and their application to VTOL aircraft.

Performance

THE OPTIMUM DESIGN OF LONG-RANGE AIRCRAFT. K. L. Sanders. Aircraft Eng., Apr., 1957, pp. 98-106. 17 refs. Method to determine the optimum aspect ratio, wing loading, and fuel-load ratio under certain specified design conditions. The basis for such calculations is an empirical wing-weight formula which represents, in a unique proportional manner, the influence of plan-form variations on wing weight. Calculations are performed for the cases of turbojet propulsion and piston airscrew propulsion, and results are plotted in diagrams.

Stability & Control

EFFECTS OF FUSELAGE NOSE LENGTH AND A CANOPY ON THE STATIC LONGITUDINAL AND LATERAL STABILITY CHARACTERISTICS OF 45° SWEPTBACK AIRPLANE MODELS HAVING FUSELAGES WITH SQUARE CROSS SECTIONS. B. M. Jaquet and H. S. Fletcher. US, NACA TN 3961, Apr., 1957. 47 pp. 10 refs. Experimental investigation, the results of which indicate that the static margin at an angle of attack of 0° is decreased by about 0.09 mean aerodynamic chord when the ratio of the fuselage nose length to the maximum depth is increased from 3.80 to 6.58. At small sideslip angles the addition of the canopy to each complete model has essentially no effect on the lift, drag, and pitching moment coefficients; however, at large sideslip angles the canopy produces some effect. An increase in the fuselage nose length causes a large decrease in the directional stability of the model whether the canopy is on or off.

Wings & Airfoils

VELOCITIES ON TWO-DIMENSIONAL CLOSED AND SEMI-INFINITE AEROFOILS AT ZERO INCIDENCE. S. Neumark and B. Thwaites. Gt. Brit., ARC R&M 2994, 1957. 14 pp. BIS, New York, $0.81. Derivation of an approximate linear method for determining the comparative two-dimensional velocity distributions on a thin, doubly symmetrical airfoil and on the corresponding semi-infinite body. The procedure provides a simple general proof that the supervelocity at the mid-chord station of a closed, doubly symmetrical profile of any shape is approximately halved when the rear half is replaced by a semi-infinite parallel body. An exact solution of the velocity distribution is obtained for one particular semi-infinite profile and several alternative examples are studied by the linear method.

WING SECTION DESIGN FOR SWEPT-BACK WINGS AT TRANSONIC SPEEDS. A. B. Haines. (Appl. Mech., 9th Internatl. Conf., Brussels, 1956.) J. RAeS, Apr., 1957, pp. 238-244. Analysis of the performance of finite swept-wings, the results of which show that the pressure distributions for sections near the root and tip are distorted in shape from what would be obtained on an infinite sheared wing and, thus, that the isobars tend to lose some or all of their sweep. The isobars are calculated using linearized theory together with certain semi-empirical approximations. Methods are presented for improving the isobar patterns, and applied to the design of a new wing.

AN APPLICATION OF AEROBALLISTICS RANGE TECHNIQUES TO MODELS WITH DIAGONAL ROTATIONAL SYMMETRY. G. H. Tidy and M. E. Thomas. (Aero. Range Symposium, Proc., Jan., 1957.) US, Army Bal. Res. Lab., Aberdeen, Rep. 1005, Pt. I, Mar., 1957, pp. 219-240. Test results on a series of flat-plate wings of triangular planform fired at Mach Numbers of 1.5 and 2. Preliminary manual reduction of the data is presented and the derived values of some aerodynamic stability coefficients are compared with linear theory.

THE LINEARIZED SUBSONIC FLOW ABOUT SYMMETRICAL NONLIFTING WING-BODY COMBINATIONS. J. B. McDevitt. US, NACA TN 3964, Apr., 1957. 67 pp. 18 refs. Derivation of an analytical method for determining the linearized subsonic flow about symmetrical, nonlifting wing-body combinations, and presentation of a theory for calculating the flow about circular or noncircular bodies by using axially distributed sources and multipoles. The flow over thin, nonlifting airfoils having symmetrical profiles is also studied in detail, and a comparison is made between theory and experiment for two 45° sweptback wings in combination with basic Sears-Haack bodies of revolution and in combination with basic bodies indented according to Whitcomb's transonic area rule.

LIFT TO DRAG RATIOS OF CERTAIN MID-WING MONOPLANE CONFIGURATIONS IN SUPERSONIC FLIGHT. Appendix I - DERIVATION OF WAVE DRAG FORMULAE WHEN WING EXTENDS BEYOND FUSELAGE MACH ENVELOPE. Appendix II - MAXIMUM LIFT TO DRAG RATIO OF WING-PLUS-FUSELAGE WHEN FUSELAGE CARRIES ONLY A FRACTION OF OPTIMUM LOAD DISTRIBUTION. M. E. Graham. Douglas Rep. SM-22626, Oct., 1956. 28 pp. 12 refs. Calculations of lift-to-drag ratios, for flight at an optimum lift coefficient, from drag values obtained previously by Licher. The drag formulas are extended to include cases when the wing lies partly outside the fuselage Mach envelope. The configuration is a Jones elliptic plan-form wing symmetrically mounted on a supersonically area-ruled Sears-Haack fuselage. The fuselage may carry a lift distribution, but no net lift. Mach Number, the intensity of the fuselage loading, and four independent geometric parameters may be varied.

AEROELASTICITY

ON THE NATURAL FREQUENCY OF SWEPT CANTILEVERED RECTANGULAR PLATE. Shinichi Suzuki. J. Japan Soc. Aero. Eng., Mar., 1957, pp. 1-4. In Japanese. Analysis involving the addition of several factors to Martin's empirical formula for apparent elastic axis. The effective length is found which coincides with experimental values up to a very small aspect ratio.

ANALYSIS OF STATIC AEROELASTIC BEHAVIOR OF LOW-ASPECT-RATIO RECTANGULAR WINGS. J. M. Hedgepeth and P. G. Waner, Jr. US, NACA TN 3958, Apr., 1957. 21 pp. Study of the divergence behavior of a constant-thickness wing when chordwise deformations are considered. The spanwise variation of the deflection is restricted to a parabola, but the chordwise variation is allowed complete freedom. Results show the variation of the divergence speed and mode shape with the aspect ratio. Comparisons are made with results obtained by using approximate chordwise deflection shapes.

EXPERIMENTALLY DETERMINED NATURAL VIBRATION MODES OF SOME CANTILEVER-WING FLUTTER MODELS BY USING AN ACCELERATION METHOD. P. W. Hanson and W. J. Tuovila. US, NACA TN 4010, Apr., 1957. 46 pp. Discussion of a technique for measurement of mode shapes of small-wing models. Three-dimensional views are presented for the first three natural-vibration mode shapes of ten contilever-wing modes. A table of normalized deflections at six spanwise and five chordwise stations is included for each mode. These mode shapes are measured by an unique experimental technique using grains of sand as accelerometers. The technique, which is particularly suited for measuring mode shapes of small-wing models, is discribed and some of the difficulties likely to be encountered are discussed.

INCOMPRESSIBLE FLUTTER CHARACTERISTICS OF REPRESENTATIVE AIRCRAFT WINGS. C. H. Wilts. US, NACA TN 3780, Apr., 1957. 121 pp. 11 refs. Detailed study of four representative wings, using the CIT electric analog computer. Eight parameters of each wing are varied and the effects of mass, inertia, pitching spring, and location of concentrated mass are investigated for all four wings and several sweepback angles. Includes discussion of the general flutter characteristics of airplanes, the pertinent electric-analog principles, and the aerodynamic and structural approximations used to simplify flutter analysis. Information relating to the errors introduced by the finite-difference approximations to continuous aeroelastic systems is given, in addition to data on the flutter characteristics of a swept-wing wind-tunnel model and the results of computations based on two assumptions regarding aerodynamic forces on a swept wing.

INVESTIGATION OF THE EFFECT OF AN IMPROVED STRIP THEORY FOR SWEPT WINGS ON THE FLUTTER SPEED. A. C. A. Bosschaart and A. I. v. d. Vooren. Netherlands, NLL TN F. 168, Sept. 10, 1956. 14 pp. Calculations, with results in the form of diagrams, of the nondimensional flutter speed as a function of the natural frequency ratio between wing bending and torsion. These calculations are based on an improved strip theory derived by van de Vooren and Eckhaus for swept wings, and are performed for the bending-torsion flutter of two types of wings with 45° sweepback. For the first type, which has a constant chord along the span, aspect ratios of 4 and 8 are considered, while the other type has a taper ratio of 1/3 and an aspect ratio of 4. A bending-torsion aileron-flutter calculation is also performed for the tapered wing fitted with a statically balanced aileron over the outer half of the span. All the results are compared with those obtained from the theory of Barmby, Cunningham, and Garrick.

SOLUTION OF AEROELASTIC PROBLEMS BY MEANS OF INFLUENCE COEFFICIENTS. D. Williams. J. RAeS, Apr., 1957, pp. 247-251. Analysis which shows that, on the basis of the data provided by two sets of influence coefficients for a wing - an elastic set giving deflections in terms of applied loads, and an aerodynamic set giving aerodynamic loads in terms of incidence angles - all static aeroelastic problems can easily be solved by using a digital computer. It is suggested that the same method may be used for solving oscillatory aeroelastic problems such as flutter.

THE RESPONSE OF AN AIRPLANE TO RANDOM ATMOSPHERIC DISTURBANCES. F. W. Diederich. US, NACA TN 3910, Apr., 1957. 95 pp. 18 refs. Extension of the statistical approach to the gust-load problem, in which flight through turbulent air is considered to be a stationary random process, by including the effect of lateral variation of the instantaneous gust intensity on the aerodynamic forces. The forces obtained in this way are used in dynamic analyses of rigid and flexible airplanes free to move vertically, in pitch, and in roll. Consideration is also given to the effect of the interaction of longitudinal, normal, and lateral gusts on the wing stresses. The mean-square values, correlation functions, and power spectra of some of the aerodynamic forces required in this type of analysis are calculated for one special correlation function of the atmospheric turbulence.

EFFECT OF SPANWISE VARIATIONS IN GUST INTENSITY ON THE LIFT DUE TO ATMOSPHERIC TURBULENCE. F. W. Diederich and J. A. Drischler. US, NACA TN 3920, Apr., 1957. 59 pp. 10 refs. Calculations of the lift spectra and correlation functions for several spanwise weighting functions and various atmospheric spectra, both for the normal and the longitudinal components of turbulence. The averaging effect of the span on the lift is shown to be very similar for the normal and longitudinal components of turbulence, for the various span loadings and turbulence spectra considered, and for various angles of sweepback.

A STUDY OF AIRCRAFT RESPONSE TO SUDDEN AND GRADED WIND GUSTS BY MEANS OF A DIFFERENTIAL ANALYSER. W. R. Blunden, F. H. Hooke, and H. K. Messerle. Brit. J. Appl.

Phys., Apr., 1957, pp. 167-173. Application of a differential analyzer to the solution of the response of rigid and flexible aircraft, allowing for lift-lag effects. The lift-lag functions are represented by exponential expressions. Includes discussion of the speed and accuracy of the results obtained.

AIRPLANE DESIGN

DESIGN OF AIR FRAMES FOR NUCLEAR POWER. C. L. Johnson and F. A. Cleveland. Aero. Eng. Rev., June, 1957, pp. 48-57. Discussion of the problems associated with nuclear-powered aircraft as offered by certain power-plant characteristics. These characteristics are a) a highly concentrated weight in the reactor, b) a powerful radiation field emanating from the reactor, and c) unlimited flight endurance. Weight and lack of space in the crew compartment design, the need for heavy landing gear, the lack of "winter relief" for the wing structure due to the nearness of the engine to the reactor, difficulties in maintenance, damage to structural materials due to radiation, and electronic equipment difficulties due to the ionized field about the aircraft are some of the design difficulties presented. Possible remedial actions are discussed. Certain advantages are accrued, such as no appreciable performance loss from extra weight additions due to "growth" and a lesser vulnerability than a chemical-fueled aircraft to battle damage.

Windshields

DEVELOPMENT OF AN INTEGRALLY BONDED EDGE ATTACHMENT SYSTEM FOR AIRCRAFT GLASS ASSEMBLIES. G. K. Partain and R. D. Kantner. USAF WADC TR 57-19 [AD 110709], Dec., 1956. 62 pp. 21 refs. Discussion showing that use of the described bonding system and an integrally bonded intermediate fiber-glass-reinforced attachment member, in conjunction with tempered glass assemblies, successfully maintains loaded efficiency throughout a greater temperature range (-65° to 500°F.) and during more severe thermal shock and radiation conditions than heretofore possible with plastic aircraft transparencies.

COMPUTERS

ANALOGUE COMPUTER DEVELOPMENT WITH REFERENCE TO HELICOPTER APPLICATIONS. B. H. Venning. J. Helicopter Assn. Gt. Brit., Apr., 1957, pp. 77-96. Application of an electronic analog computer, capable of dealing with four linear second-order differential equations, to the solution of the equations arising from the analysis of the ground-resonance problem of single-rotor helicopters as treated by Coleman. The frequency stability boundaries determined from the computer agree with those obtained by the Coleman plot, and the speed at which solutions can be obtained is such that design curves can be found for a wide range of damping and stiffness in the chassis and blades. Includes a review of some of the chief features of analog computing.

FLIGHT OPERATING PROBLEMS

APPLICATION OF DYNAMIC PROGRAMING TO THE AIRPLANE MINIMUM TIME-TO-CLIMB PROBLEM. T. F. Cartaino and S. E. Dreyfus. Aero. Eng. Rev., June, 1957, pp. 74-77. Discussion of dynamic programing, a method for solving problems arising from multistage decision processes, using a simple matrix as an example. The method is then applied to a climb problem taking into account the effects of weight changes and drag corrections along the flight path. It is shown that practical climb schedules for minimum time from any starting point in the flight spectrum can be established, and that dynamic programing can also be employed to determine paths of least fuel consumption.

INSTRUMENTS

Automatic Control

INVESTIGATION OF A NONLINEAR CONTROL SYSTEM. Appendix A, B - SIMULATION OF SECOND-ORDER NONLINEAR CONTROL SYSTEM. Appendix C - BEHAVIOR OF OUTPUT IF INPUT AND INPUT DERIVATIVE ARE SIMULTANEOUSLY SMALL. Appendix D - APPROXIMATING CURVES I. Flügge-Lotz and C. F. Taylor. US, NACA TN 3826, Apr., 1957. 92 pp. Study of discontinuous variations in the coefficients of the differential equation describing the system. From analytical considerations the process of control is visualized as establishing an ensemble of linear second-order differential equations, and as switching from one equation to another in order to maintain small instantaneous error for relatively arbitrary inputs. Once physical realization is complete, simulation techniques are used to study and evaluate the performance of the nonlinear control system and to compare it with a linear system for a wide variety of inputs.

USE OF AN ADAPTIVE SERVO TO OBTAIN OPTIMUM AIRPLANE RESPONSES. Appendix - AIRPLANE HANDLING QUALITIES. Graham Campbell. Cornell Aero. Lab. Rep. CAL-84, Feb., 1957. 63 pp. 17 refs. Investigation to demonstrate the feasibility of obtaining a desirable transfer function by means of a linear adaptive servo, and to show how such a servo is uniquely applicable to airplane handling qualities. Various schematics are presented in block diagram form, and these diagrams and the response equations are manipulated in ways to illustrate the servo's possibilities. Analog simulations, including some showing the effects of servo lags, nonlinear open-loop characteristics, and the effects of external disturbances, are presented and studied. The results of these studies are given in the form of time histories. Treatment includes hand calculations of roots and time histories, and discussion of the need for a quantitative criterion for optimizing a specific system.

Flight Instruments

PRESSURE LAG IN TUBING IN AIRCRAFT INSTRUMENT INSTALLATIONS. Shin'ichiro Takeda. J. Japan Soc. Aero. Eng., Feb., 1957, pp. 7-13. In Japanese. Investigation of the lag in transmitted pressure through long pipes connected to the pitot static tube. The errors in the static tube, line mounted on an aircraft climbing or discending at a

constant rate, are measured and compared with the calculated values. The errors in the altimeter and airspeed indicator are also measured. The amplitude and phase lag of the sinusoidally changing pressure transmitted through the pipe lines are measured and compared with theoretical results.

Flow Measuring Devices

THE DISPLACEMENT EFFECT OF PITOT TUBES IN NARROW WAKES. Appendix - THE DISPLACEMENT EFFECT FOR A TWO-DIMENSIONAL CIRCULAR CYLINDER IN A SHEAR FLOW. G. B. Marson and G. M. Lilley. Coll. of Aeronautics, Cranfield, Rep. 107, Oct., 1956. 25 pp. Measurement at sub- and supersonic speeds of the apparent displacement of the effective center of a circular pitot tube from its geometric center when placed in narrow wakes. Similar effects are found at all speeds. It is found that if the tube diameter is small compared with the wake width, the displacement is toward the region of higher velocity, and is proportional to the tube outside diameter. For larger tubes the displacement is reduced and reversed in direction when the tube diameter exceeds about three times the wake width.

Temperature Measuring Devices

DESIGN OF TOTAL TEMPERATURE PROBES. Appendix A - INFLUENCE OF RATIO OF SPECIFIC HEATS OF AIR ON THE EVALUATION OF THE AIR TEMPERATURE PROBES. Appendix B - INFLUENCE OF WATER VAPOUR IN THE AIR ON THE EVALUATION OF THE AIR TEMPERATURE PROBES. Appendix C - EVALUATION OF DATA FOR TEST PROBE B. D. H. Henshaw and D. F. Daw. Canada, NAE LR-184, Jan., 1957. 97 pp. 18 refs. Presentation of design procedures for temperature probes employing bare wire thermocouples. Detailed consideration is given to the errors arising from convection, velocity, radiation, conduction, and thermal lag. Applications are made to the design of three total-temperature probes suitable for the measurement of air temperature from ground installations, low-speed aircraft, and high-speed aircraft. Performance data are presented as a function of a speed-altitude index applicable to subsonic and supersonic speeds. Flight-test data are presented and analyzed.

MATERIALS

RUPTURE STRENGTH OF SEVERAL NICKEL-BASE ALLOYS IN SHEET FORM. J. H. Dance and F. J. Clauss. US, NACA TN 3976, Apr., 1957. 24 pp. 15 refs. Investigation to determine the 100-hour rupture strengths of Inconel X, Inconel 700, Incoloy 901, Refractaloy 26, and R-235 sheet alloy, at 1,200° and 1,350°F., in both annealed and heat-treated conditions. The strongest alloys at 1,200°F. are Inconel 700 and Incoloy 901 in the heat-treated condition, with strengths of 77,500 and 76,500 psi., respectively. At 1,350°F., the strongest alloys are heat-treated Inconel 700 and R-235, with respective 100-hour strengths of 57,500 and 53,500 psi. Incoloy 901 in the annealed condition is the most ductile, with an elongation in stress rupture of 6% to 20%. In both the annealed and heat-treated conditions, the other alloys elongated only about 1% to 5%. Photomicrographs show that fractures occur predominantly in the grain boundaries.

PROBLEMS IN THE APPLICATION OF HIGH STRENGTH STEEL ALLOYS IN THE DESIGN OF SUPERSONIC AIRCRAFT. Alf Fridtjof Ensrud. SAE Natl. Aero. Meeting, New York, Apr. 2-5, 1957, Preprint 84. 42 pp. 26 refs. Discussion of the effects of aerodynamic heating on material properties and on the ultimate strength of assembled structures, and an outline of ways to alleviate the intrinsic weight penalties accompanying the use of high-density alloys at elevated temperatures. Methods are suggested for lessening the peaks of thermal stress introduced by temperature gradients during the interval of transient heating. Recent innovations are discussed (with special reference to thin-wing and fuselage design) which may effect stabilization of compression panels subjected to thermal environment. Production problems arising from the changeover to high-temperature alloys are also mentioned.

MATHEMATICS

FUNCTIONS WITH GENERALIZED GRADIENT AND GENERALIZED SURFACES. W. H. Fleming. Purdue U., Dept. Math., TN 1 (AFOSR TN 57-134) [AD 120490], Mar., 1957. 15 pp. Analysis considering functions with compact support. Results indicate that the condition I (f) finite is equivalent to the requirement that f be of bounded variation in Caesari's sense on any cube whose interior contains the support of f. For continuous functions this motion of bounded variation agrees with Tonelli's.

THE ASYMPTOTIC THEORY OF SOLUTIONS OF $\Delta u + k^2 u = 0$. W. L. Miranker. NYU Inst. Math. Sci., Div. Electromagn. Res., Res. Rep. BR-21 (AFOSR TN 57-130) [AD 120486], Apr., 1957. 48 pp. 22 refs. Study of the theory of solutions, u, for the reduced wave equation defined in infinite domains. New proofs are given for three well-known theorems concerning u. These are Rellich's growth estimate, the uniqueness theorem for the exterior boundary-value problem, and the representation theorem. Rellich's growth estimate is extended to the case of the reduced wave equation in a medium with a variable index of refraction. It is shown that the normal boundary values of a radiating solution, u, are bounded by a homogeneous quadratic functional of its boundary values. Finally the behavior of u when the parameter k becomes large is considered.

RESOLUTION DE DIVERS PROBLEMES DU TYPE STOKES-BELTRAMI POSES PAR LA TECHNIQUE AERONAUTIQUE. Pierre Brousse. France, Min. de l'Air PST 323, 1956. 67 pp. 59 refs. SDIT, 2, Av. Porte-d'Issy, Paris 15, Frs. 1,200. In French. Resolution of varied problems of the Stokes-Beltrami type. Includes the Dirichlet problem of the equation (Ev) and of the general domain D; functions V(M) and W(M) in a half-circle whose diameter is on Ox; integral representation of solutions in the D domain; and examples and applica-

tions covering the determination of certain Green's functions, eigenfunctions, and Fourier-Bessel series development.

A NEW METHOD OF SOLVING EIGENVALUE PROBLEMS. P. Shuleshko. Australian J. Appl. Sci., Mar., 1957, pp. 7-26. 35 refs. Derivation of a technique for solving problems of rectangular-plate buckling by reduction to simpler buckling problems. Such reduction is shown to be possible under certain conditions, which, for orthotropic rectangular plates and plates beyond the elastic range, are represented by simultaneous equations. Using these equations, a critical force or stress for these plates can be computed without solving complicated eigenvalue equations. Among the other problems for which the procedure is applicable are that of obtaining a solution for a plate with certain boundary conditions if the solution for the plate with another boundary condition is known, and that of a plate with a certain biaxial loading if the solution for a plate with uniaxial loading is known.

ON THE OSCILLATION OF SOLUTIONS OF SELF-ADJOINT LINEAR DIFFERENTIAL EQUATIONS OF THE FOURTH ORDER. Walter Leighton and Zeev Nehari. Carnegie Inst. Tech., Dept. Math., TR 16 (AFOSR TN 57-102) [AD 120451], Mar., 1957. 88 pp. 14 refs. Systematic investigation of the oscillation properties of solutions to two particular types of differential equation and to those which can be transformed into one or the other of these classes. In both cases consideration is given mainly to topics familiar from the theory of separation and comparison theorems, and of oscillation criteria; phenomena which have no analogue in the second-order case also appear, however. Includes discussion of those aspects of eigenvalue problems arising in the theory of the vibrating rod to which the study of the first class of equations considered is related.

MILITARY AVIATION & ARMAMENT

MEASUREMENT AND SUPPRESSION OF TENSION WAVES IN ARRESTING GEAR ROPE SYSTEMS. J. M. N. Willis, S. W. Chisman, and N. I. Bullen. Gt. Brit. ARC R&M 2981, 1957. 26 pp. BIS, New York, $1.44. Experiments to measure the effect of the tension waves induced in an arresting gear-rope system after engagement, and to try out means of suppressing these waves with a view to application to projected arresting gears for entry speeds up to 120 and 150 knots. Results indicate that the amplitude of the tension waves becomes relatively greater with increase of entry speed and reaches very serious proportions at the maximum speeds obtained. Extensive reductions in peak tensions - up to 30% under some conditions - are achieved with the use of resilient rope anchorages.

MISSILES

TWO AEROBALLISTIC RANGE TOPICS. I - MASS ASYMMETRY. J. E. Long, G. Parrish, and J. D. Nicolaides. II - DYNAMIC STABILITY. J. D. Nicolaides. (Aero. Range Symposium, Proc., Jan., 1957.) US, Army Bal. Res. Lab. Aberdeen, Rep. 1005, Pt. I, Mar., 1957, pp. 183-218. 17 refs. I - Development of a simple approximate theory for the free-flight motion of ballistic missiles having mass asymmetry. II - Analysis of the epicyclic theory for flight dynamics of ballistic missiles in which the parameter of nutation half-life, precession half-life, and total motion half-life are suggested as better criteria for missile dynamics than those classically based on linear theory. Also a summary of important nonlinear cases of ballistic-missile flight performance is given.

PHYSICS

MEASUREMENTS OF THE ENERGY ABSORPTION IN RADIATION FIELDS OF ELECTRON SOURCES. A. E. Grün. Max-Planck-Inst. für Phys. Strato. TN 1 (AFOSR TN 57-118) [AD 120471], 1957. 19 pp. 12 refs. Investigation using the luminescence of the air as a measure of the energy absorption $\alpha(z)$ of air in the radiation field of a special electron source. $\alpha(z)$ is measured as a function of the penetration depth z (depth dose curves) and is evaluated for primary electron energies (E_0) ranging from 5 to 54 keV. A power law is found for the range R of the electrons as a function of E_0.

NIGHT-TIME IONIZATION IN THE LOWER IONOSPHERE. I - RECOMBINATION PROCESSES. II - DISTRIBUTION OF ELECTRONS AND POSITIVE AND NEGATIVE IONS. A. P. Mitra. J. Atmos. & Terrestrial Phys., Mar., 1957, pp. 140-162. 20 refs. USAF-sponsored investigation of the nature of the night-time variation of certain ionospheric parameters, such as height, electron density, and absorption over a frequency range of 16 kc./sec. to 18.3 mc/sec, in order to deduce the time and height variations of the effective coefficient of recombination for heights in the range 80 to 110 km. From these observational results, the distributions of various positive and negative ions and of electrons are deduced.

POWER PLANTS

Jet & Turbine

RESEARCH ON APPLICATION OF COOLING TO GAS TURBINES. J. B. Esgar, J. N. B. Livingood, and R. O. Hickel. (ASME Semi-Annual Meeting, Cleveland, June 17--21, 1956.) Trans. ASME, Apr., 1957, pp. 645-651. 45 refs. Discussion to show when it is desirable to use cooling in gas-turbine engines, and to present relevant results obtained at the Lewis Flight Propulsion Laboratory. It is shown that such cooling provides increased turbine-inlet temperature which causes higher tail-pipe jet velocities and, thus, greater thrust for turbojet engines and increased turbine-shaft power for engines such as the turboprop; increased turbine stress levels; and increased turbine reliability. Design considerations are given for cooled turbine engines, and several air- and liquid-cooling methods are described and evaluated.

ACTUATOR DISC THEORIES APPLIED TO THE DESIGN OF AXIAL COMPRESSORS. A. D. Carmichael and J. H. Horlock. Gt. Brit., ARC CP 315, 1957. 18 pp. BIS, New York, $0.54. Derivation of a relatively simple method for find-

ing the flow conditions near blade rows when the variation in whirl or tangential velocity is known. Solutions to the radial equilibrium equations are given for a useful variation in whirl velocity; this variation provides constant radial work rotors and includes the free vortex and constant reaction designs as particular solutions. The combination of these results gives a useful design method for axial compressors.

INVESTIGATION OF SEMIVANELESS TURBINE STATOR DESIGNED TO PRODUCE AXIALLY SYMMETRICAL FREE-VORTEX FLOW. H. E. Rohlik and W. T. Wintucky. US, NACA TN 3980, Apr., 1957. 39 pp. Development of a turbine stator designed to eliminate blade wakes and secondary-flow accumulations of boundary-layer air. Performance of this stator is evaluated by use of static pressures measured in the vaneless section and by surveys of total pressure and flow angle made at the stator exit. Results indicate that the semivaneless stator sets up a free-vortex flow which is substantially free of circumferential gradients in flow angle and total pressure. Loss in total pressure across the stator is slightly greater than that measured with a conventional stator designed for the same exit-flow conditions.

ESTIMATION OF THE CHANGE IN PERFORMANCE CHARACTERISTICS OF A TURBINE RESULTING FROM CHANGES IN THE GAS THERMODYNAMIC PROPERTIES. D. G. Ainley. Gt. Brit., ARC R&M 2973, 1956. 13 pp. BIS, New York, $0.72. Approximate method of correcting turbine characteristics for differences in the gas thermodynamic properties (geometric dimensions being unaltered) when turbines are tested in a laboratory with cool air used to represent the hot gas for which the turbine is designed. Results of this procedure, which is additionally useful in turbine-performance calculations, also indicate the order of magnitude of the changes in the gas thermodynamic characteristics resulting from variations in annulus area and blade tip at shroud clearances.

INVESTIGATION OF A FULL-SCALE, CASCADE-TYPE THRUST REVERSER. R. C. Kohl and J. S. Algranti. US, NACA TN 3975, Apr., 1957. 53 pp. Test results of a thrust reverser that is installed in a single-engine turbojet airplane. A reverse-thrust ratio of about 35% is obtained at full engine speed. Reverse-thrust ratios up to 56% are obtained by increasing the thrust reverser inlet velocity. Supplementary scale-model, unheated-air tests indicate a 3% loss of forward thrust due to stowage of the turning vanes inside the tailpipe. Taxi tests on a dry asphalt-macadam runway indicate that the average aircraft deceleration is about 0.11 g's when using either wheelbrakes or thrust reverser alone; in combination, the average deceleration is doubled.

Rocket

ON GENERALIZED SCALING PROCEDURES FOR LIQUID-FUEL ROCKET ENGINES. S. S. Penner and A. E. Fuhs. AMF TD TR 104 (AFOSR TN 56-510) [AD 110325], Oct. 10, 1956. 23 pp. Generalization of the Penner-Tsien, Crocco, and Barrere scaling procedures by assuming that the mean drop size is proportional to the product of powers of the Weber Number and the Reynolds Number, and that the total conversion time varies as a power (usually the second) of the drop diameter. The results obtained for the steady aerothermochemistry and for unstable motor operation (low-frequency and high-frequency oscillations) are shown to reduce to previously published rules when suitable simplifying assumptions are made.

OPTIMUM THRUST PROGRAMING FOR HIGH-ALTITUDE ROCKETS. G. Leitmann. Aero. Eng. Rev., June, 1957, pp. 63-66. Development of a thrust-time relation to achieve the optimum compromise between reduction in gravity and drag losses, thereby minimizing fuel expenditure. It is concluded that the ideal thrust program can be approximated by a realistic program - one with a high-thrust phase in place of impulsive boost - without greatly affecting summit altitude. Whether or not added complexity of controlling the thrust is worth the gain over best constant thrust is a problem that must be answered in each particular case.

ROTATING WING AIRCRAFT

AUTOMATIC PILOTS FOR HELICOPTERS. I - THEORETICAL CONSIDERATIONS. H. Collomosse. II - FLIGHT DEVELOPMENT. M. C. Curties. J. Helicopter Assn. Gt. Brit., Apr., 1957, pp. 45-57. Analysis of the system of a single-rotor type of aircraft having three modes of operation - stabilizer, cruising, and automatic hover - and RAE flight-test verification of the theoretical results. An elementary theory is discussed which involves simple aerodynamics, gives a reasonable approximation to hovering flight, and provides a simple stability model based on physical principles. From this theory, the general form of the control law required is determined, the design of a stabilizer system based on this law is analyzed, and approximate values of the control parameters are calculated. Theory is extended to determine the control laws required for the cases of cruising and automatic hover. Flight-test results indicate the design features needed in a practical system for everyday use.

A FREE STREAMLINE THEORY FOR TWO-DIMENSIONAL FULLY CAVITATED HYDROFOILS. T. Yao-Tsu Wu. J. Math. & Phys., Oct., 1956, pp. 236-265. 18 refs. ONR-supported extension of the free streamline theory to the lifting problems of hydrofoils with a fully cavitating wake. The analysis is carried out by using the Roshko model to approximate the wake far downstream. Mathematical considerations depend on the conformal mapping of the complex velocity plane into the plane of complex potential. By using a generalization of the Levi-Civita method for curved barriers in cavity flows, the flow problem for curved hydrofoils is finally reduced to a nonlinear boundary-value problem for an analytic function defined in the upper half of a unit circle to which Schwarz's principle of reflection can be applied. The problem is then solved by using the expansion of this analytic function inside the unit circle together

with the boundary conditions in the physical plane. From the final result the various effects - such as cavitation number, camber of the profile, and angle of attack - are discussed in detail.

HELICOPTER ROTOR BLADE FLAPPING AND BENDING. II - ELASTIC BLADES. J. P. Jones. Aircraft Eng., Apr., 1957, pp. 107-112. Derivation of equations of motion from Lagrange's equations, assuming that the blade deflection can be represented by a combination of suitable modes, the coefficients of which are functions of time. Quasi-steady aerodynamic-theory is assumed, and the forces produced by the elastic deformations are taken into account. The procedure is illustrated by a simple calculation.

STRUCTURES

CERTAIN METHODS OF STRESS-ANALYSIS OF RECTANGULAR MULTI-WEB BOX BEAMS. Appendix A - ANALYSIS OF WEB SHEAR DISTRIBUTION. Appendix B - CONSTRAINT STRESS DISTRIBUTIONS. K. H. Griffin. Coll. of Aeronautics, Cranfield, Rep. 108, Dec., 1956. 21 pp. Theoretical investigation of the stress distribution in an unswept, multiweb box under shear load applied at the center of a rigid tip rib. Results are compared, with satisfactory agreement, to those obtained by a method which replaces the shear webs by a shear-carrying continuum. Includes outline of a method for performing root-constraint calculations on such a box, and results of an elementary analysis of this type are compared with experimental data.

Cylinders & Shells

BOUNDS ON INFLUENCE COEFFICIENTS FOR CIRCULAR CYLINDRICAL SHELLS. Eric Reissner and M. B. Sledd. GIT Eng. Exper. Sta. Rep. 1 (AFOSR TN 56-575) [AD 110397], Dec. 1, 1956. 33 pp. Application of the minimum principles of the theory of elasticity for displacements and for stresses to a problem involving rotationally symmetric deformations of a thin, elastic, circular cylindrical shell of variable wall thickness and of finite or semi-infinite axial length. One of the two edges of the shell is a free edge; the other is acted upon by a uniformly distributed bending moment M_o and radial force H_o. The shell deforms under the influence of the moment and force and, in particular, the edge along which M_o and H_o are applied undergoes a radial displacement and a rotation. Treatment is characterized by the fact that the bounding of several direct and inverse influence coefficients are taken into account simultaneously.

BUCKLING UNDER EXTERNAL PRESSURE OF CYLINDRICAL SHELLS EVENLY STIFFENED BY RINGS ONLY. P. P. Bijlaard. J. Aero. Sci., June, 1957, pp. 437-447, 455. 23 refs. Calculations for determining a) the critical pressure for panel buckling and b) the general instability of shells evenly stiffened by rings with equal spacings. Calculation a) is carried out by determining the length of the equivalent simply supported shell, taking into account the rotational restraints offered by the rings and, by partially neglecting the curvature of short shells, considering the limited applicability of small deflection theory, as well. Rotational spring constants are found for rings with plate and box sections. The method of split rigidities is used to perform calculation b), and reduction factors for plasticity and eccentricity are discussed. An example of this calculation is given and compared with experimental data.

THE EFFECT OF TRANSVERSE SHEAR DEFORMATION ON THE BENDING OF ELASTIC SHELLS OF REVOLUTION. P. M. Naghdi. Quart. Appl. Math., Apr., 1957, pp. 41-52. Analysis of small, axisymmetric deformations of elastic shells of revolution, where only the effect of transverse-shear deformation is retained. The basic equations, which include the appropriate expression for the transverse (shear) stress resultant due to the variation in thickness, are reduced to two simultaneous second-order differential equations in two suitable dependent variables. These equations are then combined into a single complex differential equation which is valid for shells of uniform thickness, as well as for a large class of variable thickness. Finally, by an extension of the asymptotic integration due to Langer, the general solution of the complex differential equation is presented.

THE INTERACTION OF AN ACOUSTIC WAVE AND AN ELASTIC SPHERICAL SHELL. P. Mann-Nachbar. Quart. Appl. Math., Apr., 1957, pp. 83-93. Analysis on the effect of the impact of a plane wave on an elastic spherical shell, taking into account both the incident and diffracted waves. An infinite series solution is used and numerical results are obtained for the case of a steel shell in water. It is shown that a simple quasi-static system can be used to find a very good approximation for the stress.

Elasticity & Plasticity

PLANE PROBLEMS IN SECOND-ORDER ELASTICITY THEORY. J. E. Adkins and A. E. Green. Proc. Royal Soc. (London), Ser. A, Apr. 9, 1957, pp. 557-576. 14 refs. Application of the Adkins-Green-Nicholas approximate two-dimensional theory of finite elastic deformations to problems involving infinite bodies bounded internally by simple closed contours. Expressions are derived for the force and couple resultants on a single internal boundary, and the nature of the solution for a uniform distribution of stress and strain at infinity is examined. The equations governing the deformation are expressed in a form which enables corresponding first and second boundary-value problems to be solved simultaneously. The theory is formulated in complex-variable notation, permitting solutions to be obtained by making use of the Hilbert problem along the lines developed by Muskhelishvili, et al., for classical elasticity problems. Includes examination of problems involving uniform stress and displacement distributions along a single internal circular boundary and at infinity, to illustrate the method.

BIHARMONIC EIGENVALUE PROBLEM OF THE SEMI-INFINITE STRIP. Gabriel Horvay.

Quart. Appl. Math., Apr., 1957, pp. 65-81. 14 refs. Evaluation of the stress and deformation state produced by self-equilibrating, but otherwise arbitrary, normal and shear tractions acting on the edge of a semi-infinite elastic strip. Two mixed-end problems are solved for the case in which the shear displacement is given and the normal stress is zero, and for the case in which the normal displacement is given and the shear stress is zero.

Plates

THE BUCKLING OF A CLAMPED PARALLELOGRAM PLATE UNDER COMBINED BENDING AND COMPRESSION. J. Guest. Australian J. Appl. Sci., Mar., 1957, pp. 27-34. Analysis of several different types of stress distributions, using Galerkin's variation of the Rayleigh-Ritz method to find the various critical buckling stresses. Cases studied include Case 1, which covers the problem of pure bending of clamped rhombic plates - that is, the two opposite edges are unloaded while the other two are each subjected to linearly varying tension and compression, with the midpoint as the zero stress point; Case 2, which treats the rhombic plate in pure compression in one direction, this compression being greatest at the lowest boundary, dimishing linearly, and reaching zero stress at the top corner; and Case 3, which deals with an asymmetric stress distribution in one direction, with the plate subjected to linearly varying compression along the lower third of the loaded boundaries, thence to undergo linearly varying tension for the remainder of the way up.

EXACT SOLUTION FOR CANTILEVER PLATES OF WHICHSOEVER TRAPEZIUM PLANFORM AND OF VARIABLE THICKNESS. Luigi Broglio. Roma U. Sch. Aero. Eng. Inst. Aero. Construc. Rep. SIAR 6 (AFOSR TN 57-92) [AD 120440], May, 1956. 75 pp. Analysis of the general case for swept-wing plan forms. A special system of coordinates is introduced that represents the edges of the plates as coordinate lines. The partial differential equations of the structure and the corresponding boundary conditions are transformed to an infinite set of ordinary equations. It is shown that, if the flexural rigidity of the plate in the chordwise direction varies with any law, and if the spanwise direction varies as x^n (where x is the distance from the origin, and n is any real number), an exact solution can be attained. Formulas providing the solution are given, and comparison is made between the various orders at which the chordwise expansion can be stopped.

DIE IN SCHICHTEN GLEICHER DICKE REIBUNGSFREI GESCHICHTETE HALBEBENE MIT PERIODISCH VERTEILTER RANDBELASTUNG. G. Sonntag. Forschung Gebiete Ing., Ausg. A, No. 1/2, 1957, pp. 3-8. In German. Study of a semiinfinite plane composed of frictionless superimposed layers of equal thickness and subjected to periodically distributed edge loads. When the thickness of the layers is small in comparison to the lengths of period of the load derived in the form of Fourier series, the various layers may be treated as beams. Under the conditions that even under load these beams are in continuous frictionless contact, simple formulas result for the stresses and strains.

Sandwich Structures

EXPLORATORY INVESTIGATION ON HONEYCOMB SANDWICH CONSTRUCTION FOR SUPERSONIC AIRCRAFT. B. R. Norton. Saab Sonics, No. 24, 1957, pp. 17-25. 17 refs. Review of investigations on aluminum honeycomb cores bonded to faces with adhesive films, Redux 775 and Bloomingdale FM-47. The study consists of tensile tests on cores, compressive tests on sandwich columns, and shear tests on various sandwich webs. Design curves are plotted in some cases. Further results are presented showing the influence of temperature on the shear strength of aluminum alloy core and the bonding films. Creep results are given for tests to determine the optimum curing temperature and time for applying Redux 775 to yield minimum creep values. Discussion includes remarks on various new temperature-resistant adhesives and on combinations of various materials for sandwich panels with external insulation.

Testing

STATISTICAL HANDLING OF FATIGUE DATA AND PLANNING OF SMALL TEST SERIES. Appendix - SOME GENERAL FORMULAE CONCERNING LINEAR REGRESSION. Waloddi Weibull. Sweden, Flygtekniska Försöksanstalten, FFA Medd. 69, 1957. 35 pp. Development of an analytical method for determining the parameters of the S-N equation and estimating the accuracy of computed values. General regression formulas are adapted for this purpose. The concept of linear regression imposes certain particular conditions on the choice of coordinates, and the conditions are stated and analyzed. Formulas for computation of the parameters, including the variance in fatigue strength, are derived and the variances in the parameters are deduced for the purpose of setting fiducial limits. The influence of test numbers on the accuracy of results and the best apportionment of tests among stress levels are discussed.

Thermal Stress

A PHENOMENOLOGICAL RELATION BETWEEN STRESS, STRAIN RATE, AND TEMPERATURE FOR METALS AT ELEVATED TEMPERATURES. E. Z. Stowell. US, NACA TN 4000, May, 1957. 19 pp. Study to account for the behavior of polycrystalline metals above the equicohesive temperature. The properties of the metal included in the relation are elasticity, linear thermal expansion, and viscosity. The relation may be integrated under various conditions to provide information on creep rates, creep rupture, stress-strain curves, and rapid-heating curves. It is shown that for one material - 7065-T6 aluminum-alloy sheet - the information yielded by the relation for these applications agrees reasonably well with test data.

EFFECT OF AN INTERFACE ON TRANSIENT TEMPERATURE DISTRIBUTION IN COMPOSITE AIRCRAFT JOINTS. M. E. Barzelay and G. F.

Holloway. US, NACA TN 3824, Apr., 1957. 51 pp. Investigation of geometrically related structural joints representing typical skin-stringer cross sections, tested under radiant heating to simulate the effects of aerodynamic heating. Temperature histories for 15 2024-T aluminum-alloy fabricated specimens and an equal number of integral control specimens are recorded for two different constant-heat inputs, ranging from approximately 5 to 40 BTU/ft.^{2}-sec. A maximum temperature rise of 450° F. is attained in the specimens in 8 to 40 sec. of heating. The presence of an interface is found to have a significant effect on the temperature distribution in all geometries tested and thus must be considered in temperature calculations.

ON THE EFFECT OF FLIGHT LOADS AND THERMAL STRESSES ON THE DEFORMATIONS OF WING SECTIONS AND SKINS OF HIGH SPEED AIRPLANES. I - FUNDAMENTAL EQUATIONS FOR THE THERMO-ELASTIC PROBLEMS OF A PLATE AND ITS THERMO-ELASTIC BUCKLING. Tsuyoshi Hayashi. J. Japan Soc. Aero. Eng., Feb, 1957, pp. 1-7. In Japanese. Derivation of fundamental equations for a plate which is subjected to a nonuniform temperature distribution over its surface and to external forces in its middle surface. The stress state and the deformation of a rectangular plate under a nonuniform temperature are analyzed and the conditions of thermo-elastic buckling are derived as a special case.

THE SHEAR STRENGTH AT ELEVATED TEMPERATURES OF AN ALUMINIUM ALLOY HONEYCOMB CORE BONDED TO LOADING PLATES WITH TWO TYPES OF ADHESIVE FILMS. B. R. Noton. Sweden, Flygtekniska Försöksanstalten, FFA Medd. 72, 1957. 35 pp. 15 refs. Investigation, at temperatures up to 100°C., of honeycomb cores bonded with either Bloomingdale FM-47 or Redux 775 adhesive films. In room-temperature tests the mean longitudinal shear strength of the core is approximately 22 kg./cm.^{2} and the transverse shear strength 12.6 kg/cm^2. At 70°C. the mean reduction in the longitudinal shear strength is only 7% for Redux 775 and 4% for FM-47. At 100°C. this reduction is 36% and 38%, respectively. Thus, for the temperature investigated, the results show that there is only a small difference in the mean shear strength of the core when bonded with Redux 775 and FM-47.

THERMODYNAMICS

ANALYSIS OF HEAT-DRIVEN OSCILLATIONS OF GAS FLOWS. H. J. Merk. Appl. Sci. Res., Sect. A, No. 4, 1957, pp. 317-336. 19 refs. Derivation of a theoretical method for treating heat-driven oscillations. The fundamental ideas underlying the theory are discussed with reference to a simple model consisting of a tube containing a disc-shaped heat source perpendicular to the axis of the tube. It is shown that the existence of the entropy mode of oscillations, which is present along with the acoustic mode downstream of the heat source, can be neglected if the effects of the viscosity and Mach Number on the oscillation are slight enough to permit neglect of quadratic and higher terms in these parameters. Transfer functions of the heat source are introduced together with acoustic admittances and impedances in order to obtain the characteristic equation governing the occurrence of heat-driven oscillations. This equation is derived from the laws of conservation of momentum and energy applied across the heat source.

ETUDE DE LA CONVECTION PAR LES FILS AUX FAIBLES NOMBRES DE REYNOLDS. Jean Gosse. France, Min. de l'Air PST 322, 1956. 89 pp. 36 refs. SDIT, 2, Av. Porte-d'Issy, Paris 15, Frs. 1,200. In French. Study of the convection of wires at low Reynolds Numbers. Includes discussion of the temperature distribution in thin, electrically heated wires in permanent regime, subjected to the cooling effect of a fluid flow whose direction is perpendicular to that of the wire. The law of longitudinal temperature distribution is determined, taking into account simultaneous variations of electric and thermal conduction as function of temperature.

Combustion

FURTHER EXPERIMENTS ON THE STABILITY OF LAMINAR AND TURBULENT HYDROGEN-AIR FLAMES AT REDUCED PRESSURES. Burton Fine. US, NACA TN 3977, Apr., 1957. 31 pp. 15 refs. Measurement of stability limits as a function of pressure, burner diameter, and composition. The average pressure exponent of the critical boundary velocity gradient for turbulent flashback is 1.31, which is not significantly different from the laminar value. The use of a simple flame model and measured turbulent flame speeds indicates that turbulent flashback can involve a smaller effective penetration distance than laminar flashback. Turbulent blowoff velocity is nearly independent and varies about as the inverse square root of the burner diameter. Extrapolation of stability loops to the quenching point shows that the quenching pressure is inversely proportional to the burner diameter. The actual pressures are higher than those obtained by other quenching measurements.

STABILITY LIMITS OF FLAMES OF TERNARY HYDROCARBON MIXTURES. P. F. Kurz. Comb. & Flame, Mar., 1957, pp. 3-13. Description of the behavior of ternary mixtures of ethylene, propane, and isobutane at the lean and rich blow-off limits and at flashback on a Bunsen flame shielded by an inert gas. Only laminar flames are studied. Data are presented to show the behavior of each of the component fuels burning in a binary mixture with air, and these results are used to interpret the data obtained when ternary fuel mixtures burning with air are studied. Each component of the ternary mixture is used, in turn, as the primary fuel.

SOME LIMITING OXYGEN CONCENTRATIONS FOR DIFFUSION FLAMES IN AIR DILUTED WITH NITROGEN. R. F. Simmons and H. G. Wolfhard. Gt. Brit., RAE TN R.P.D. 151, Feb., 1957. 12 pp. Experimental investigation in which fuels are burned at the surface of a porous hemispherical burner of stainless steel in order to determine the nitrogen

concentration required to extinguish the flame. Results are given for a number of fuels in terms of the limiting oxygen index, and it is found that these values are close to those obtained for premixed flames. Results of flame-temperature calculations for these limit mixtures indicate that a given mixture will only burn if its flame temperature exceeds the limiting flame temperature for that fuel.

THE CONSERVATION EQUATIONS FOR INDEPENDENT COEXISTENT CONTINUA AND FOR MULTICOMPONENT REACTING GAS MIXTURES. W. Nachbar, F. Williams, and S. S. Penner. Lockheed Aircraft Co., LMSD 2082 (AFOSR TN 56-458) [AD 97074], Mar. 15, 1957. 20 pp. 16 refs. Derivation of the conservation laws for multicomponent reacting gas mixtures. A physical model is invented that is consistent with continuum theory. The model involves the idea of a multicomponent continuum composed of coexistent continua, each obeying the laws of dynamics and thermodynamics. It is shown that, with proper identifications, these conservation equations are those obeyed by real gas mixtures.

SPECTRA PRODUCED BY SHOCK WAVES, FLAMES AND DETONATIONS. A. R. Fairbairn and A. G. Gaydon. Proc. Royal Soc. (London), Ser. A, Apr. 9, 1957, pp. 464-475. 23 refs. Comparison between emission spectra excited in various gases, including fuel and fuel + argon mixtures, by strong shock waves from a bursting diaphragm and emission spectra given by flames and by spark-ignited and shock-ignited detonations. Formaldehyde, ether, alcohols, ethyl nitrate, carbon tetrachloride, and chloroform are also studied. Time records are obtained for emissions from detonations by using a photomultipher and an oscillograph, and the relation of these results to the propagation mechanism is briefly discussed. It is shown that shock-excited spectra resemble those produced by flames rather than those from discharge tubes - apparently pointing the way to a promising technique for studying fundamental processes in flames.

VOLUMETRIC RATES OF ENERGY RELEASE CHARACTERISTIC OF DIFFERENT MECHANISMS OF TURBULENT COMBUSTION IN PREMIXED GASES. R. R. John. ARDE Assoc. TN 4555-4 (AFOSR TN 57-5) [AD 115036], Dec., 1956. 24 pp. 21 refs. Study of volume rates of energy release in a wrinkled laminar flame, in the zone of extended reaction, and in the zone of instantaneous mixing. Emphasis is placed on the space-heating-rate (SHR) characteristic of the zone of extended reaction. On the basis of the absolute value and the pressure dependence of the SHR, it is suggested that the zone of extended reaction is the turbulent combustion process occurring in contemporary continuous-flow combustion systems.

CONTRIBUTION TO THE KNOWLEDGE OF REACTION KINETICS IN PREMIXED LAMINAR FLAMES. A. Van Tiggelen. Louvain U., Inorg. & Anal. Chem. Lab. TR (AFOSR 57-27) [AD 126445], Feb., 1957. 99 pp. 34 refs. Theoretical investigation of a theory for flame propagation based on the kinetics of chain reactions, with emphasis on the branching condition in the propagation. The theory gives a good correlation between different flame properties and even between flames propagating in mixtures of different fuels and oxidants. Measurements of flame temperature, burning velocity, and flame-front thickness are made in mixtures of various fuels and oxidants. Overall activation energies, assumed to be approximately equal to the activation energy of the branching process, are derived from experimental data. The intensity of different bands emitted in the flame spectra are also measured.

AN EXPERIMENTAL INVESTIGATION OF TWO-DIMENSIONAL TURBULENT MIXING OF PARALLEL COMPRESSIBLE JETS AT LARGE TEMPERATURE DIFFERENCES AND APPROXIMATELY EQUAL MACH NUMBERS. R. E. Walker. Johns Hopkins U., APL Bumblebee Ser. Rep. 232, May, 1955. 78 pp. 33 refs. Theoretical and experimental investigation of two-dimensional mixing of subsonic gas streams at nearly equal Mach Number and large temperature differences. Parallel gas streams at temperature ratios of approximately 5.0, 6.6, and 7.4 are studied. High temperatures are obtained by the combustion of hydro-carbon fuel and the Mach Numbers in both streams are maintained at approximately 0.24. Temperature and Mach Number profiles in the mixing are obtained with a pneumatic temperature probe. The experimental temperature profiles in the mixing zone are correlated to fit both an error integral curve and the profiles derived from the vorticity-transfer theory. Comparison with published data is made to show that the divergence of mixing is independent of the temperature ratio above about 2 when the composite data are correlated to a common profile.

FLAME ZONE STUDIES. III - TECHNIQUES FOR THE DETERMINATION OF COMPOSITION PROFILES OF FLAME FRONTS. R. M. Fristrom, R. Prescott, and C. Grunfelder. Comb. & Flame, Mar., 1957, pp. 102-113. 16 refs. Description and evaluation of a method in which a quartz microprobe is used to select small samples of the flame gases at various known positions. These samples are then withdrawn, quenched, and analyzed. The probe position, relative to the luminous zone of the flame, is determined photographically. Critical experiments are cited to show the existence of a single set of composition profiles that uniquely describe a laminar flame front and to establish that the given techniques accurately and reproducibly determine these profiles.

PRELIMINARY EVALUATION OF A ROTATING FLAME STABILIZER. J. H. Grover, M. G. Kesler, and A. C. Scurlock. (ARS Fall Meeting, Buffalo, Sept. 24--26, 1956.) Jet Propulsion, Apr., 1957, pp. 386-391. ONR-sponsored investigation of the feasibility of rotating a bluff flame holder as a means of increasing volumetric heat-release rates in high-output combustion chambers. A

cylindrical flame holder with its longitudinal axis normal to the flow of combustible gas is rotated rapidly about a transverse axis parallel to the flow. This rotation results in the generation of a flame at higher rates than when the flame holder remains stationary, and volumetric heat-release rates are correspondingly increased. Rotation, however, tends to reduce the stability limits. For any one tailpipe length, the combustion efficiency increases with increasing rate of rotation. The power required to overcome the rotational drag is calculated to be usually less than the losses due to wall friction or to the axial drag of the flame holder.

Heat Transfer

EXPERIMENTAL STUDY OF HEAT TRANSFER TO SMALL CYLINDERS IN A SUBSONIC, HIGH-TEMPERATURE GAS STREAM. Appendix A, B - EVALUATION OF HEAT-TRANSFER COEFFICIENT FOR CYLINDER IN CROSSFLOW UNDER FORCED CONVECTION AND RADIATION. Appendix C - METHOD USED TO COMPUTE VISCOSITY AND THERMAL CONDUCTIVITY OF COMBUSTION GAS MIXTURES. G. E. Glawe, R. C. Johnson, and R. S. Brokaw. US, NACA TN 3934, May, 1957. 21 pp. 11 refs. Derivation of a Nusselt-Reynolds Number relation for cylindrical thermocouple wires in crossflow from the experimental determination of time constants. Tests are conducted in exhaust gas over a temperature range of 2,000° to 3,400° R., a Mach Number range of 0.3 to 0.8, and a static-pressure range from 2/3 to 1 1/3 atmospheres. Combinations of these conditions yield a Reynolds Number range of 450 to 3,000, based on wire diameter.

STEADY STATE HEAT TRANSFER TO FULLY DEVELOPED TURBULENT FLOW IN A CURVED CHANNEL. A. W. Marris. Can. J. Phys., Apr., 1957, pp. 411-434. 12 refs. Development of a vorticity-transfer analogy theory of turbulent heat transfer, first considering the case of fully developed turbulent flow under zero transverse pressure and temperature gradients - such as that in the annulus between concentric cylinders rotating with different angular velocities or in a free vortex. An argument is given to show that the boundary-layer thickness should be of the order of the reciprocal of the square root of the mean velocity, and Nusselt moduli are defined and their dependence on Reynolds and Prandtl numbers is investigated. The temperature distributions are obtained for the case of flow in a curved channel in which the fluid does not flow back into itself, and the applicability of the simpler equations for zero transverse gradients to this case is investigated.

WATER-BORNE AIRCRAFT

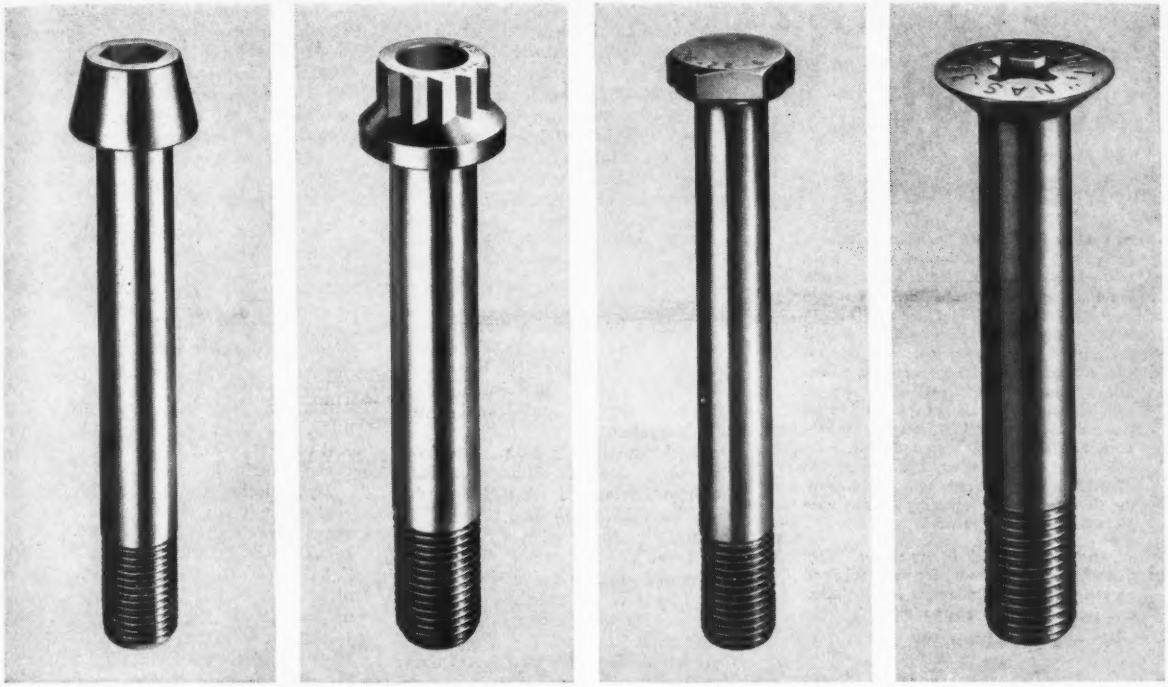
AN EXPERIMENTAL HYDRODYNAMIC INVESTIGATION OF THE INCEPTION OF VORTEX VENTILATION. J. A. Ramsen. US, NACA TN 3903, Apr., 1957. 31 pp. Tests using three modified flat plates - all of aspect ratio 0.25, but differing in scale and thickness ratio - to study some of the parameters affecting the inception of vortex ventilation. Results show two distinct bubble-formation processes for all three models, and indicate that the speed of inception of the planing bubble in the high angle-of-attack range varies only slightly with angle of attack but increases considerably with increasing depth of submersion; that the speed of inception of the planing bubble in the low angle-of-attack range increases significantly with decreasing angle of attack and only slightly with increasing depth of submersion; and that the speed of inception for the two models differing only in scale is the same, whereas the model differing in thickness ratio is brought into correlation by expressing the speed as a function of the thickness ratio.

WIND TUNNELS & RESEARCH FACILITIES

WAKE VISUALIZATION STUDIES IN THE AEROBALLISTICS RANGE. G. V. Bull and C. B. Jeffery. (Aero. Range Symposium, Proc., Jan., 1957.) US, Army Bal. Res. Lab., Aberdeen, Rep. 1005, Pt. I, Mar., 1957, pp. 127-148. Presentation of a new method of flow visualization by the interaction of hydrochloric acid and ammonia hydroxide vapors. A plane sheet of laminar smoke filaments is produced in the range, and models developing lift due to incidence are fired through this sheet. Spark and fortax photography are used to record the development of the wake profile. Wake distortions and vortex formations are studied for several types of bodies and compared with computations based on linear theory.

ADVANCES IN THE DYNAMIC ANALYSIS OF RANGE DATA. C. H. Murphy. (Aero. Range Symposium, Proc., Jan., 1957.) US, Army Bal. Res. Lab., Aberdeen, Rep. 1005, Pt. I, Mar., 1957, pp. 45-83. 13 refs. Methods for analyzing pitching and yawing motion and its associated aerodynamic coefficients. Four cases are discussed: first the classical case - the dynamic analysis of thrustless symmetric missiles acted on by linear aerodynamic forces and moments; then a gun-boosted burning-rocket program fired on the transonic range is described and the minor alterations to the data analysis are indicated; next the problem of an asymmetrical-finned missile with a roll rate varying through resonance is considered; and finally the successful treatment of cubic nonlinearities in static and Magnus moments and their associated forces are described.

SURVEY, CALIBRATION, AND REDUCTION TECHNIQUES USED AT THE THOMPSON AEROBALLISTICS LABORATORY. W. H. Allan and E. L. Dunn. (Aero. Range Symposium, Proc., Jan., 1957.) US, Army Bal. Res. Lab., Aberdeen, Rep. 1005, Pt. I, Mar., 1957, pp. 85-125. Analysis of the photogrammetric problem of reducing data from the Thompson Aeroballistics Laboratory. Includes a description of the precise position survey, the photographic calibration of the cameras to furnish transformation equations, the use of the transformation equations to yield position and orientation of the missile, alternate solutions for position and orientation, solutions for roll orientation, and results of the reduction as applied to several typical rounds.



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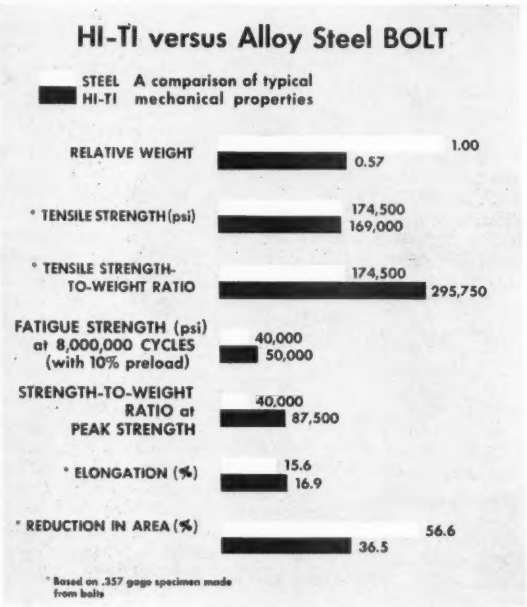

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Materials

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MICHAEL SCALZO
Graduated from Purdue, B. S. in Aeronautical Engineering 1948 and joined Bell in 1952 as a Preliminary Design Engineer. He later became Project Engineer for Weapon System Requirement and Analysis and today, at 33, he is Chief of the Installation Design Department, Aircraft Division.

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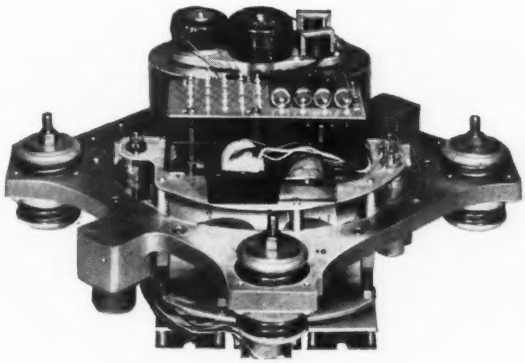

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Rocket

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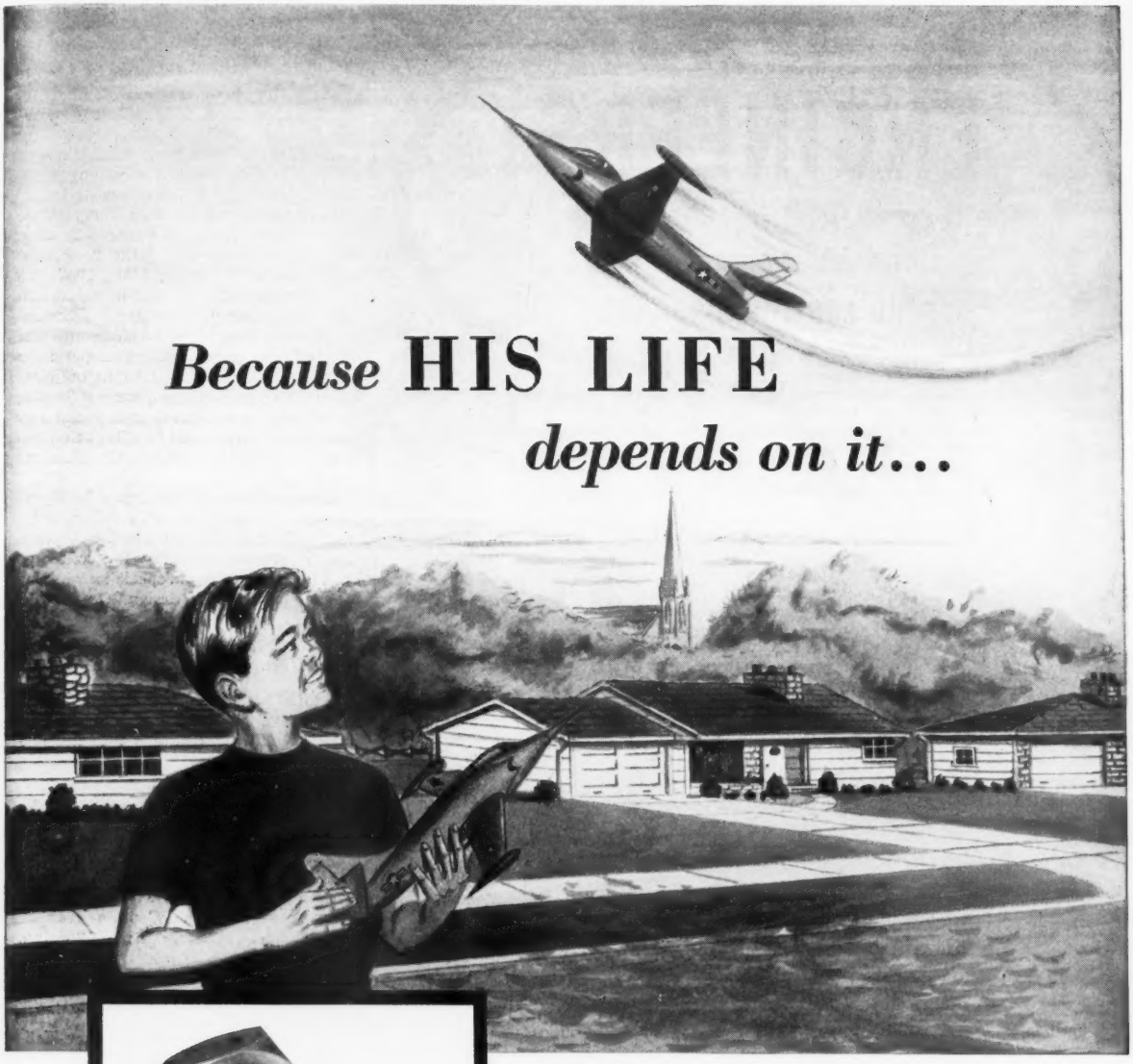

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(*Continued on page 172*)

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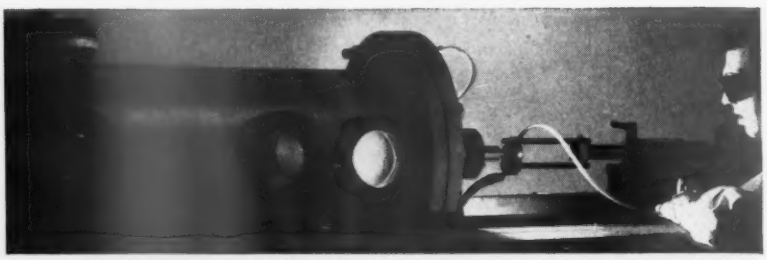
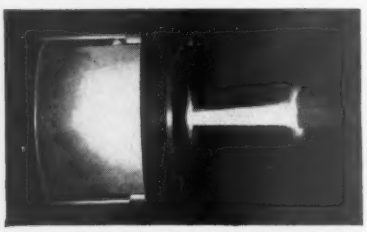
Meteors may melt on entering the earth's atmosphere, but the relatively thin-skinned nose cone must come through in full functional order. To test out heat-resistant materials capable of withstanding re-entry temperatures, a new instrument was devised under the direction of the research staff of MOSD.



STABILIZED WATER ARC and G-E designed TUNNEL shown during operation. Material undergoing test is held in front of the arc orifice by means of a rod or "sting" running through the tunnel.

3000 KW used in operating this stabilized arc and evacuation tunnel. (Shown idle.) Has ¼" nozzle diameter. Present plans call for construction of a 3" diameter model, requiring 8,000 KW for operation.



View of fluid-stabilized arc in operation. The liquid revolving inside the glass or plastic cylinder flowing at high velocity offers insulation as well as the material of which the plastic beam is composed.

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Aeronautical Reviews — BOOKS

AERODYNAMICS

Aerodynamic Components of Aircraft at High Speeds. Edited by A. F. Donovan and H. R. Lawrence. (High Speed Aerodynamics and Jet Propulsion, Vol. 7.) Princeton, N.J., Princeton University Press, 1957. 845 pp., illus., diagrs., tables. $17.50.

The purpose of this volume is to present a comprehensive and competent treatment of the fundamentals of the aerodynamics of high-speed flight which are of direct interest to aircraft designers. The several contributors concern themselves primarily with the applications to wings (in both steady and unsteady motion), bodies, interference effects, propellers, diffusers, and nozzles. Items dealing with the aircraft as a whole, such as performance, aeroelasticity, and stability and control, will appear in Volume 8, *High Speed Problems of Aircraft and Experimental Methods*, scheduled for publication in the spring of 1958.

Contents: A, Aerodynamics of Wings at High Speeds, Robert T. Jones and Doris Cohen, NACA, Ames Aeronautical Laboratory. B, Aerodynamics of Bodies at High Speeds, Clinton E. Brown, NACA, Langley Aeronautical Laboratory. C, Interaction Problems, C. Ferrari, Politecnico di Torino, Italy. D, Propellers for High Speed Flight, C. B. Smith, Pratt & Whitney Aircraft Division, United Aircraft Corporation. E, Diffusers and Nozzles, J. C. Evvard, NACA, Lewis Flight Propulsion Laboratory. F, Nonsteady Wing Characteristics, I. E. Garrick, NACA, Langley Aeronautical Laboratory (Hunsaker Professor of Aeronautics, M.I.T., 1956–1957). G, The Experimental Aerodynamics of Wings at Transonic and Supersonic Speeds, C. W. Frick, NACA, Ames Aeronautical Laboratory. Index.

Viscous Flow Theory; Vol. 2, Turbulent Flow. Shih-I Pai. Princeton, N.J., D. Van Nostrand Company, Inc., 1957. 277 pp., diagrs. $6.75.

In this companion volume to *Laminar Flow* (described in the January, 1957, issue of the REVIEW) Dr. Pai, who is Research Professor, Institute for Fluid Dynamics and Applied Mathematics, University of Maryland, discusses the most important experimental and theoretical facts of turbulent motion from the point of view of the advanced student in fluid dynamics. To this end he first examines the fundamentals of turbulent flow, noting that its primary characteristic is the random nature of the fluctuations which govern the velocity and pressure distributions, as well as energy loss in the flow of real fluids.

Chapters 2 through 7 are devoted to the study of turbulent flow of both compressible and incompressible fluids as explained by semiempirical or phenomenological theory. This includes turbulent flow in pipes and channels, boundary-layer flow with and without a pressure gradient, and the free turbulence problems of jet mixing and wakes. Chapters 8 through 14 discuss the application of classical statistical mechanics to the turbulence problem of fluid mechanics and the corresponding status of the statistical theory of turbulence as it has evolved during the last 20 years, particularly for the homogeneous and isotropic case. Topics such as probability distribution, turbulent diffusion, and the correlation tensors of turbulence appear here.

Also included are such lines of investigation as the spectrum function of turbulence, the theory of isotropic turbulence, and turbulence in a compressible fluid flow and in the important new area of study known as magnetohydrodynamics.

High-Speed Aerodynamics (Compressible Flow). Elie Carafoli. Bucharest, Editura Tehnica, 1956. 710 pp., diagrs., tables, folding charts.

This book is the English translation of the Rumanian work, *Aerodinamica Vitezelor Mari*, which was published in Bucharest in 1956 and dealt with high-speed aerodynamic phenomena, including subsonic and supersonic flows. Following a physicomathematical introduction to his subject which summarizes the fundamentals of vector analysis and the basic relations of thermodynamics, Dr. Carafoli concerns himself primarily with the problems of the flow of compressible fluids with special emphasis on the influence of the speed of sound in establishing the equations of motion in their various forms.

Much of the book is taken up with a study of subsonic two-dimensional flows and flows around bodies of revolution, assuming small disturbances, and with particular application to wings of finite span. The material on supersonic flow treats of two-dimensional flow, the flow around bodies of revolution, and the theory of conical flow. The expansion of a two-dimensional supersonic stream is discussed, and the theory of supersonic profiles is developed. The closing chapters are devoted to an analysis of the effects of supersonic speeds on tapered and triangular wings and to a consideration of certain aspects of unsteady flow at high speeds. The author is Director of the Research Institute for Applied Mechanics and Professor of the Polytechnic Institute in Bucharest.

Contents: (1) Preliminary Physico-Mathematical Introduction. (2) Fundamental Relations Concerning the Motion of Compressible Fluids. (3) Steady One-Dimensional Flow. (4) General Subsonic Flow. Considerations on the Transonic Regime. (5) Supersonic Flow in the Case of Small Disturbances. (6) Rigorous Solutions in Two-Dimensional Supersonic Flow. (7) Exact Solutions in Flow Around Bodies of Revolution. (8) The Theory of Wings of Finite Span in Supersonic Flow, Based on the Method of Small Disturbances. (9) Complex Flows Around Triangular Wings and Their Application in Determining Aerodynamic Characteristics.

AERONAUTICS, GENERAL

Aircraft Yearbook, 1956. Editors: Fred Hamlin and Eleanor Thayer Miller. 38th Ed. Aircraft Industries Association of America, Inc. Washington, Lincoln Press, Inc., 1957. 484 pp., illus., diagrs. $6.00.

Contents: Aviation Books Published in the United States in 1956, Arthur G. Renstrom. Summary Statistics. Aviation Events, 1956. The Industry: Aircraft, Engines, Propellers, Systems and Components. Department of Defense. Government Agencies in Aviation. Manpower. Research and Development. Guided Missiles. The Airlines. Utility Aircraft. Helicopters. Planes in Production (Photographs, Descriptions, and Three-View Drawings of Aircraft Being Produced in 1956). Engines in Production. 1956 Day by Day Chronology. A Chronology of U.S. Aviation. Directory of Information Sources. Official Records. Index.

U.S. Aviation Today, 1957. 4th Ed. Aircraft Industries Association. Washington, National Aviation Education Council, 1957. 94 pp., illus., diagrs. $0.35.

Designed to enrich the aviation curriculum in schools, this edition reviews outstanding events and achievements in aviation during 1956. It includes illustrations and descriptions of civil and military aircraft currently in production.

AIR TRANSPORTATION

Forecast of the United States Domestic Air Passenger Market, 1965–1975. New York, Forecast and Analysis Division, Aviation Department, Port of New York Authority, January, 1957. 102 pp., diagrs., tables.

This forecast has been prepared to provide the framework for guiding the physical and economic planning of PONYA air terminal facilities, which must meet estimated traffic requirements and be economically self-liquidating during their estimated term of service.

AIRCRAFT

High-Speed Flight. E. Ower and J. L. Nayler. London, Hutchinson & Company; New York, Philosophical Library, 1957. 227 pp., illus., diagrs., tables. $10.

The purpose of this nontechnical account of a complex subject is to introduce the layman and workers in branches of science and engineering other than aeronautical engineering to the many new problems raised by flight at speeds equivalent to the speed of sound in air, or faster. The fundamentals of flight are explained and methods of research and experimentation in aerodynamics, propulsion, structures, and materials are reviewed. Some account is also given of modern rockets and guided missiles. Mr. Ower is a former Secretary to the Scientific Advisory Council, British Ministry of Supply, and Mr. Nayler is Secretary, Aeronautical Research Council.

Famous Fighters of the Second World War. William Green. Illustrated by G. W. Heumann. London, MacDonald & Company; New York, Hanover House, 1957. 128 pp., illus., diagrs. $3.95.

Eighteen of the best-known fighter planes of World War II are described in detail, from conception through the different variational developments to operational performances. Photographs, specifications, and diagrams with full insignia, camouflage, squadron and individual markings, are given for each combat aircraft.

For Information on IAS Library Services, see page 117

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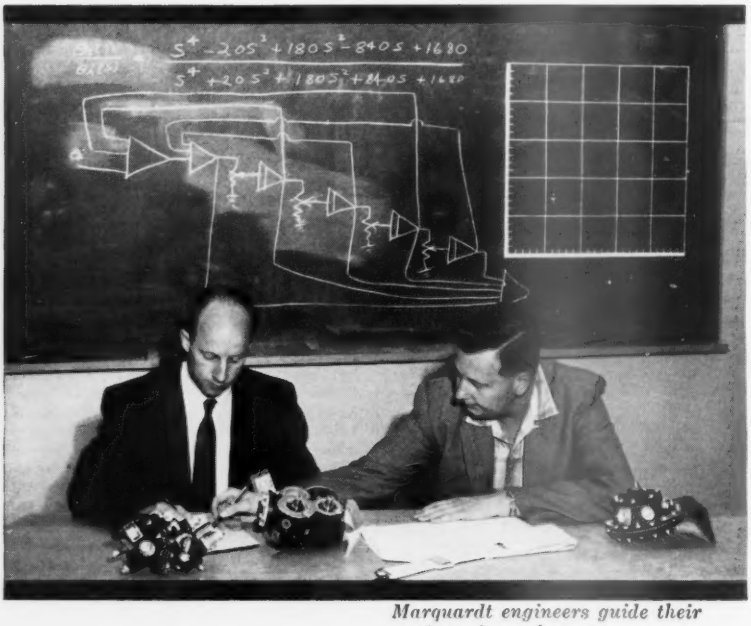

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AIRPLANE DESIGN

British Civil Airworthiness Requirements, Section C: Engines and Propellers, Issue No. 4. London, Air Registration Board, March 1, 1957. 100 pp., diagr., tables. 8*s*.

AUTOMATION

Automation in Business and Industry. Edited by Eugene M. Grabbe. New York, John Wiley & Sons, Inc., 1957. 611 pp., illus., diagrs., tables. $10.

Based on a series of lectures given in 1955 by prominent engineers and scientists at the University of California, this collective work provides an integrated and detailed approach to the fundamentals of automation, new developments in automation, techniques, and the applications of automation systems. The treatment is general rather than technical, with many of the papers being accompanied by bibliographies for purposes of further study. The editor is Lecturer in Engineering, University of California, Los Angeles.

Contents: Introduction—Reflections on Automation, L. M. K. Boelter. (1) Automation in Business and Industry, Simon Ramo. (2) The Language of Automation, E. M. Grabbe. (3) Fundamentals of Automation, John L. Barnes. (4) Feedback Control Systems, Harold Chestnut. (5) Basic Concepts of Industrial Instrumentation and Control, Herbert W. Ziebolz. (6) Analog Computers, Stanley Fifer. (7) Digital Computers, Willis H. Ware. (8) Data Processing, John W. Mauchly. (9) Analog-to-Digital Conversion Units, Bernard S. Benson and George G. Bower. (10) Input-Output Equipment, Walter F. Bauer. (11) Applications of Electronic Data-Processing Machines, Cuthbert C. Hurd. (12) Automatic Control of Flight, Duane T. McRuer. (13) Automatic Production of Electronic Equipment, L. K. Lee. (14) Process Control in the Petroleum and Chemical Industries, C. G. Laspe. (15) Analog Computers in Industrial Control Systems, E. L. Harder. (16) Digital Control of Machine Tools, John L. Bower. (17) Manufacturing Automation, R. W. Bolz. (18) Economics of Plant Automation, Frank K. Shallenberger. (19) The Future of Automation, Dean E. Wooldridge.

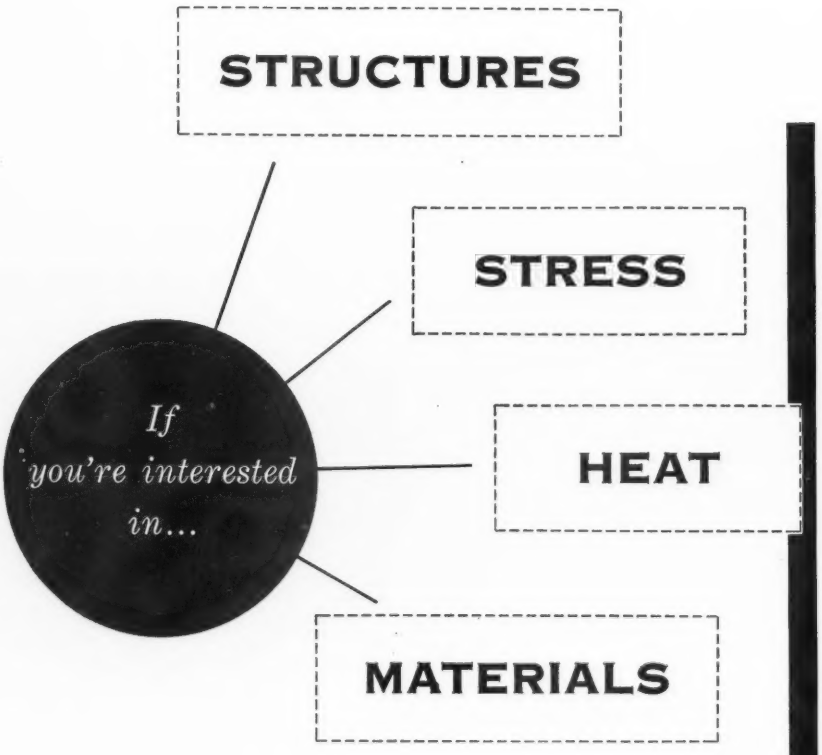
Automation: Its Purpose & Future. Magnus Pyke. London, Hutchinson & Co. Ltd.; New York, Philosophical Library, 1957. 191 pp. illus., diagrs. $10.

This book reviews the progress of automation in mass-production industries and in office work since the perfection of the electronic computer made possible the precise control of machines by other machines. The author is particularly concerned with the social effects likely to stem from widespread adoption of automatic techniques and devotes the final chapters of his book to a discussion of the economic factors involved and the possible nature of an "automatic" world.

Contents: (1) Industrial Work, New Style. (2) The Electronic Computer. (3) Automatic Engineering. (4) Automatic Chemistry. (5) The Petroleum Industry. (6) Automatic Accounting. (7) Automation and Transport. (8) Automatic Shops. (9) Automation in Food and Catering. (10) Guided Missiles. (11) Automatic Translation. (12) Automation—How Soon? (13) Life Automatic.

CHEMICAL ENGINEERING

Chemical Engineering Practice; Vol. 3, Solid Systems. Edited by Herbert W. Cremer and Trefor Davies. London, Butterworths Scientific Publications; New York, Academic Press,



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The ONLY magazine serving the specialized interests of professional engineers and design project teams in the aviation industry.

Inc., 1957. 534 pp., illus., diagrs., tables. $17.50.

Contents: Size Reduction: Principles of Crushing and Grinding, Harold Heywood. Methods of Sizing Analysis, Harold Heywood. Crushing and Grinding Equipment, J. C. Farrant and R. North. The Mechanics of Pulverizers, Harold Heywood. Special Applications of Grinding Machines, R. A. Scott. *Screening, Grading and Classifying*, R. A. Scott. Tabling and Jigging, G. H. Higginbotham. Flotation, J. E. Felstead. Sedimentation, R. Forbes Stewart. Wet Classification, R. Forbes Stewart. Dense Medium Coal Washing, R. Symington. Air Flow Selection, R. A. Scott. *Mixing of Solids*, R. A. Scott. *Storage and Handling of Solids*, J. A. W. Huggill. Sampling, Measuring and Gauging of Solids, E. J. Sebestyen. *Cleaning Gaseous Media:* Cyclones, R. F. Heinrich and J. R. Anderson. Electro-Precipitation, R. F. Heinrich and J. R. Anderson.

COMMUNICATIONS

Communication Engineering. W. L. Everitt and G. E. Anner. 3rd Ed. New York, McGraw-Hill Book Company, Inc., 1956. 644 pp., diagrs., tables. $9.00.

The field of communication engineering has expanded considerably since the appearance of the second edition of this work in 1937; consequently the authors, while retaining the title, have not attempted to cover the entire field. In this edition emphasis has been placed on the area which must precede the study of all other divisions of communication—namely, the fundamentals of linear-network analysis and synthesis, including the use of unilateral elements. In order to demonstrate the design requirements which are imposed on the linear portions of communications systems networks, the book develops both an analysis of various types of modulation and the transformation of transients from the time to the frequency domain.

Major additions to the third edition include a broader treatment of mesh and nodal analysis of general networks; a more general treatment of reactance networks, including methods of network synthesis; a more general treatment of long lines; low-loss line analysis and synthesis by means of bicircular and Smith charts; a broader treatment of filters and equalizers; the general use of normalization and symmetry to make analysis more universal; the losses in impedance transforming networks; broadband impedance transformation systems using both lumped and distributed network elements; and broadband linear amplifiers.

The authors are, respectively, Dean, College of Engineering, and Associate Professor of Electrical Engineering, University of Illinois.

COMPUTERS

Mathematics and Computers. George R. Stibitz and Jules A. Larrivee. New York, McGraw-Hill Book Company, Inc., 1957. 228 pp., illus., diagrs., tables. $5.00.

The subject of this book is the part played by computing devices in the important applications of mathematical thought to problems in science, technology, and business. The principal emphasis is on the capabilities and limitations of automatic digital computers, although nondigital devices are also covered. The importance of random sequences in computational methods is thoroughly explained, and some examples of computer applications are given.

Contents: (1) Mathematics, Computers, and Problems. (2) Applied Mathematics and Solutions. (3) Kinds of Problems and Where They Come From. (4) History of Computers. (5) Numerical Analysis. (6) Digital Computer Components. (7) Logical Design of Digital Computers. (8) Analog Computers and Simulators. (9) Computing with Random Numbers. (10) Computer Errors. (11) Computers at Work. Appendix A: Selected Bibliography. Appendix B: Some Examples of Computer Applications. Author Index. Subject Index.

DICTIONARIES

Dizionario di Tecnica dei Razzi e d'Astronautica (A Technical Dictionary of Rockets and Astronautics). Glauco Partel. (Associazione Italiana Razzi.) Rome, Istituto Poligrafico dello Stato G. C., 1955. 1,107 pp. L. 1000.

This multilingual dictionary of 1,316 terms was compiled by Mr. Partel, Fellow of the Associazione Razzi, for the purpose of assembling for workers in astronautics and rocketry the terms peculiar to their specialized fields. To ensure maximum completeness and accuracy, the text was submitted to the American Rocket Society, the British Interplanetary Society, and the Gesellschaft für Weltraumforschung for criticism and revision. The French text was supplied by E. Leygue, editor of Docaéro. Italian terms are listed first, with their German, English, and French equivalents tabulated in adjacent columns. There are separate indexes for German, English, and French which enable the user to locate the equivalent term in the other languages.

DIRECTORIES

Aviation Directory of Canada, 1957. 2nd Ed. An "Aircraft" Publication. Toronto, Farm Equipment Publishing Company, Ltd., 1957. 174 pp., illus., diagrs. $5.00.

This completely revised edition contains listings of the following segments of Canadian aviation: the aircraft industry, the air transport industry, military aviation, government departments and organizations, aviation organizations and publications, insurance agencies, and sources of aviation supplies and services. The "Who's Who" section presents biographical information on some 400 persons prominent in the Canadian aeronautical scene.

ELECTRONICS

National Telemetering Conference, 1956; Papers Presented at Los Angeles, August 20–21, 1956. Sponsored by American Institute of Electrical Engineers, Institute of the Aeronautical Sciences, Institute of Radio Engineers, and Instrument Society of America. New York, Institute of Radio Engineers, 1956. 130 pp., illus., diagrs. $3.50; available from sponsoring agencies.

A printing of the technical papers presented at the conference, with the exception of those by Leever, and Prast and Hartmann, which appear only in abstract form. The papers by D. W. Blancher and W. J. Ross, though listed in the Table of Contents, were not available for inclusion at the time of publication.

Contents: Session I, Systems I: A Wide Bandwidth Telemetry System, D. E. Henry and R. E. Glass. Advanced Design Telemetry for Vehicles Subjected to Severe Environmental Conditions, D. W. Blancher. Radio-Frequency Link Design for Telemetering, Hans Scharla-Nielsen. Beacon Telemetering System, Stanley Berinsky. Performance Characteristics of Time and Frequency Multiplexed Telemetering Systems, H. S. McGaughan.

Session II, Data Processing: A New Development in the Processing of PDM Telemetry Data, W. E. Leever. An Automatic Data Reduction System for Pulse Width Telemetry, F. T. Chambers. A Method of Separating Vibration Data into its Frequency and Amplitude Components, John M. Hawk. A High-Speed, High-Accuracy Automatic Digital Data Reduction System for FM and PWM Telemetered Information, William Kroll.

Session III, Components and Equipment: Temperature Measurements on High Speed Missiles, George E. Reis. Measurement of Millivolt Data by Pulse Width Multiplexing, W. J. Ross. A Method of Commutating Low Level Signals, Owen Ott. Commutation and Amplification of Low Level Signals, W. J. Ross. Frequency Stability Investigations on FM/FM Telemetering Equipment, Johannes W. Prast and Karl F. Hartmann.

Session IV, Panel: Crowding of the Telemetering Frequency Bands, George S. Shaw

Session V, Systems II: An Integrated Sub-Miniature Digital Airborne Ground Data Transmission System, Bernard M. Gordon. Pulse Coded Messages Over Radar Beacon Equipments, Kurt Merl and Richard Rabin. A Comparison of Encoding Techniques for Telemetry and Data Handling, R. A. Runyan. A Wide Band Radio Link Telemetering System, T. D. Warzecha. Tone Code Telemetry System for Event Data, Daniel Luchter.

Session VI, Recorders: A High Speed, General Purpose, Magnetic Tape Data Recorder for Use with a Digital Computer, Edmond R. Pelta, Direct Writing, Continuous Recording Above 100 Cycles Per Second, Herbert L. Chambers and John C. Riedel. A Miniature Digital Recorder, Charles P. Hedges. A New Small Digital Data Printer, Edgar A. Hilton and Harold Elliot.

Session VII, Components and Equipment II: Receiver Design Considerations for Future Telemetry Requirements, R. E. Grimm. A Continuously Tunable Discriminator for FM/FM Telemetering Systems, Glenn E. Tisdale. A Transistorized Telemetering System as a Watch Dog on Guided Missile Performance, Fred M. Riddle. Transistors Applied to an Operational FM/FM Telemetry System. C. B. McCampbell, R. H. Gablehouse, P. S. Scheele, and R. P. Matthews.

Session VIII, Panel: Telemetry Techniques in Flight Testing of Aircraft, J. J. Dover.

Proceedings of the Second RETMA Conference on Reliable Electrical Connections, University of Pennsylvania, September 11, 12, 1956. Sponsored by the Engineering Department, Radio-Electronics-Television Manufacturers Association; Co-Sponsored by Advisory Group on Electronics Parts, Department of Defense. New York, Engineering Publishers, 1957. 103 pp., illus., diagrs., tables. $5.00.

Contents: How Reliable Is That Connection, W. H. Rombach. Equipment Selection for Soldering, H. C. Sohl. Importance of Surfaces, Fluxes and Solders, F. C. Disque, Jr. Operator Influence on Reliability of a Soldered Connection, H. R. Kellogg. Some Observations of Techniques in the Preparation of and Soldering to Printed Wiring Boards, John Madden. Contamination by Fluxes in Printed Wiring Soldering, S. W. Chaikin. Solderable Wire Coatings, Ralph Hall. Experimental Evaluation of the Reliability of Solderless Wrapped Connections, R. H. Van Horn. Industry Survey Questions and Answers. Index to Questions and Answers. Reliability of Tool Applied Pressure Connectors, H. B. Gibson. Solderless Connectors, Franklin H. Wells. Silver Brazing of Electrical Connections, A. W. Swift. Ultrasonic Joining, J. B. Jones.

Reliability Factors for Ground Electronic Equipment. Keith Henney, Editor in Chief. (USAF, Rome Air Development Center.) New York, McGraw-Hill Book Company, Inc., 1956. 245 pp., illus., diagrs., tables. $7.50.

The repeated failure of many items of military electronic equipment to function reliably for extended periods of time has lead many private and Governmental agencies to develop criteria and techniques to aid the equipment designer in overcoming this serious problem. The numerous reasons why electronic equipment does not have the necessary reliability are discussed in this book, which also surveys earlier efforts to examine the entire electronic reliability situation and to develop measures that would result in reliable equipment requiring a minimum of maintenance. Many engineers representing both military users and manufacturers contributed to this text, the publication of which was made possible through the support and sponsorship of the General Engineering Laboratory of the Rome Air Development Center. Literature references and bibliographies are numerous.

Contents: (1) Reliability Concepts. (2) Causes of Unreliability. (3) Systems Aspects. (4) Mathematical Approach to Reliability. (5) Electrical and Electronic Factors. (6) Mechanical and Environmental Factors. (7) Human Engineering. (8) Component Parts. (9) Interference. (10) Automatic Production. (11) Equipment Publications. (12) Maintenance.

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MECHANICS

Mechanics for Engineers: Statics and Dynamics. Ferdinand P. Beer and E. Russell Johnston, Jr. New York, McGraw-Hill Book Company, Inc., 1957. 673 pp., diagrs. $8.00.

This text is designed for the first courses in statics and dynamics offered to engineering students in their sophomore or junior years and requires no mathematical knowledge beyond algebra, trigonometry, and the differentiation and integration of elementary functions. One of the characteristics of the approach used is that the mechanics of particles has been clearly separated from the mechanics of rigid bodies, making it possible to consider simple practical applications at an early stage and to postpone the introduction of the more difficult concepts.

The section on statics deals primarily with the equilibrium of rigid bodies and includes material on the concepts of instability and statical indeterminacy. The second section, on dynamics, covers kinematics and the kinetics of elementary rigid body systems. Additional topics considered are graphical methods for the analysis of coplanar forces, applications to hydrostatics, shear and bending-moment diagrams for beams, equilibrium of cables, products of inertia and Mohr's circle, the method of virtual work, problems of central forces, deflections of fluid streams, problems involving jet and rocket propulsion, Coriolis acceleration, gyroscopes, and damped mechanical vibrations.

Free-body diagrams are introduced early in the text, and emphasis is placed on these "free-body-diagram equations" rather than on the standard algebraic equations of motion. Each topic is divided into three parts: new material, sample problems, and problems assigned for solution. The authors are Professor of Mechanics and Associate Professor of Civil Engineering, respectively, Lehigh University.

METEOROLOGY

Weather Elements; A Text in Elementary Meteorology. Thomas A. Blair. Revised by Robert C. Fite. 4th Ed. Englewood Cliffs, N.J., Prentice-Hall, Inc., 1957. 414 pp., illus., diagrs., tables. $6.75.

Intended as an introduction to advanced study in the subject, this revised edition takes note of new concepts and techniques, including artificial rain stimulation, which have been developed in the field of meteorology since 1948. The technical descriptions and mathematical formulas have been promulgated at college freshman level. Each chapter concludes with a group of problems which require for their solution an understanding and application of the textual material. Nearly 150 illustrations are used to support the discussions. The reviser of the work is Professor of Geography and Meteorology, Oklahoma A. and M. College.

NATURAL FLIGHT

Biology and Physics of Locust Flight. (Royal Society of London, Philosophical Transactions, Series B, Biological Sciences, No. 667, Vol. 239, July 26, 1956, pp. 415-585.) London, Royal Society of London, 1956. 170 pp., diagrs., tables. 55*s*.

Contents: (1) Basic Principles in Insect Flight, A Critical Review, T. Weis-Fogh and Martin Jensen. (2) Flight Performance of the Desert Locust (Schistocerca Gregaria), T. Weis-Fogh. (3) The Aerodynamics of Locust Flight, Martin Jensen. (4) Notes on Sensory Mechanisms in Locust Flight, T. Weig-Fogh.

NUCLEAR ENERGY

World Wide Industrial Role of Nuclear Energy. John Jay Hopkins. New York, General Dynamics Corporation, 1956. 119 pp., illus., diagrs.

The new economic potential of atomic energy and the attendant role of the individual and the nation are discussed in this study by the Chairman of the Nuclear Energy Committee of the National Association of Manufacturers and the President of General Dynamics Corporation. Mr. Hopkins

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PHYSICS

American Institute of Physics Handbook. Dwight E. Gray, Coordinating Editor. Sponsored by American Institute of Physics. New York, McGraw-Hill Book Company, Inc., 1957. 1,523 pp., diagrs., tables. $15.

This inclusive reference work, prepared as a tool for those employing physical methods in research, application, and teaching, is the first handbook specifically on physics to be published in the United States, and the first such volume to be sponsored by the American Institute of Physics. More than one hundred subject areas are covered in eight individually paged sections: mathematics, mechanics, heat, sound, electricity and magnetism, optics, atomic and molecular physics, and nuclear physics. Each of the subsections is the work of specialists who have contributed a wide range of physical topics, including tables, graphs, and summaries of formulas in all the fields of physics.

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The individual Section Editors are Albert A. Bennett, Brown University; Bruce H. Billings, Baird-Atomic, Inc.; D. F. Bleil, U.S. Naval Ordnance Laboratory, White Oak, Md.; G. H. Dieke, The Johns Hopkins University; Floyd A. Firestone, Acoustical Society of America; F. N. D. Kurie, U.S. Navy Electronics Laboratory; R. Bruce Lindsay, Brown University; Mark W. Zemansky, City College of New York. Dwight E. Gray, Coordinating Editor, is Program Director for Government Research Information, National Science Foundation.

STRUCTURES

The Plastic Methods of Structural Analysis. B. G. Neal. New York, John Wiley & Sons, Inc., 1956. 353 pp., diagrs., tables. $7.50.

The plastic methods of structural analysis have been developed for the purpose of calculating the plastic collapse loads for frames of mild steel with the ultimate objective of establishing a rational and economical design procedure. In this book Dr. Neal, Professor of Civil Engineering and Chairman of Engineering Department, University College of Swansea, gives an account of certain basic assumptions concerning the behavior of structural members in flexure which should be of interest to practicing structural engineers, research workers, and undergraduate students. No attempt has been made to describe the present state of the investigations into the problem of elastic-plastic buckling, although references are given to this work whenever appropriate.

Contents: (1) Basic Hypotheses. (2) Simple Cases of Plastic Collapse. (3) Plastic Collapse—Basic Theorems and Simple Examples. (4) General Methods for Plastic Design. (5) Estimates of Deflections. (6) Factors Affecting the Fully Plastic Moment. (7) Minimum Weight Design. (8) Variable Repeated Loading. Appendix A: Plastic Theory and Trusses. Appendix B: Plastic Moduli of British Standard Beams. Appendix C: Proofs of Plastic Collapse Theorems. Appendix D: Proof of Shake-Down Theorem. Answers to Examples. Author Index. Subject Index.

THERMODYNAMICS

Engineering Thermodynamics. C. Osborn Mackey, William N. Barnard, and Frank O. Ellenwood. New York, John Wiley & Sons, Inc., 1957. 428 pp., diagrs., tables. $7.95.

This presentation of the fundamentals of heat and power engineering is a completely rewritten version of the 3rd edition of *Heat-Power Engineering*, which appeared in 1933, and embodies the developments and advances in the field since then. The first six chapters are concerned with basic principles of engineering thermodynamics, including the properties and processes of real gases. The remaining eight chapters cover such topics as one-dimensional flow of ideal gases with area change, friction and heat transfer, properties of mixtures of ideal gases, ideal gas reactions, energy transformations in turbines, power cycles with real fluids, refrigeration, and air conditioning.

Professor Mackey, Head of the Department of Thermal Engineering, Cornell University, has prepared his material to be used as a college and university text for the engineering student with the proper prerequisites of mathematics, physics, chemistry, and mechanics. Exercises, selected to illustrate the application of the basic principles, are given at the end of each chapter.

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Aeronautical Reviews *(Continued from page 162)*

curved profile based on the Kirchhof method.

Wind Tunnels & Research Facilities

Nature's Simulator. George A. Warner. *Instrumentation*, Mar.-Apr., 1957, pp. 4–7. Description of climatic chambers for testing newly designed ground electronic equipment under widely varying environmental conditions.

Missile Parts Leakage Tested with Pressurized Helium. Victor DeBiasi. *Av. Age*, Apr., 1957, pp. 66–71 ff. Description of the Robertshaw-Fulton Controls Co. helium-pressurization facility for testing missile and aircraft parts for such critical parameters as zero leakage.

Erfahrung - ohne Risiko. Manfred Jäger. *Flug-Revue*, Feb. 23, 1957, pp. 7–11. In German. Description and evaluation of research and simulator installation.

Steam Jet Vacuum Pumping for Large Altitude Chambers. Ronald M Bykowski. *Environmental Quart.*, 1st Quart., 1957, pp. 4–6, 14, 21. Discussion pointing out the advantages of steam-jet vacuum pumping which include large-volume capacity at low pressures, low initial and maintenance costs, ruggedness, compactness, and ease of operation.

Data Reduction Center Clears Way for Missile Research. *Ind. Labs.*, Apr., 1957, pp. 48, 49 ff. Description of the equipment and methods employed in The Ramo-Wooldridge Corp. data-reduction center, for converting telemetered performance information into a form suitable for study and analysis.

Blow the Missile Down. M. R. Mulkey. *CEC Recordings*, Mar.-Apr., 1957, pp. 3–5. Description of AEDC's "blow-down" wind tunnel E-1—which has a Mach Number range of 1.2 to 5.5—in terms of its flexibility, the electromanometers used, its two-way system, and its simulation of free-flight conditions.

The R.A.E. 4-ft × 3-ft Experimental Low-Turbulence Wind Tunnel. II—Measurements of Turbulence Intensity and Noise in the Working-Section. *Gt. Brit., ARC R&M 2905* (Mar., 1951), 1957. 19 pp. 12 refs. BIS, New York, $1.08.

A Simple Method for Photographing Transparent Objects. L. J. F. Broer, A. Deeleman, and J. A. Rietdijk. *Appl. Sci. Res., Sect. B*, No. 4, 1957, pp. 253–258. Method of photographing expansion waves and shocks in a supersonic jet using a simple optical device. The method is less sensitive to mechanical disturbances than schlieren photography.

Low Speed Flow Studies of the Vortex Patterns Above Inclined Slender Bodies Using a New Smoke Technique. R. L. Maltby and D. H. Peckham. *Gt. Brit., RAE TN Aero.2482*, Nov., 1956. 12 pp. Description of a simple method to render visible the vortex-flow pattern above an inclined body in a low-speed tunnel. Includes examples of such flow and identification of two main types of vortex patterns at high incidence.

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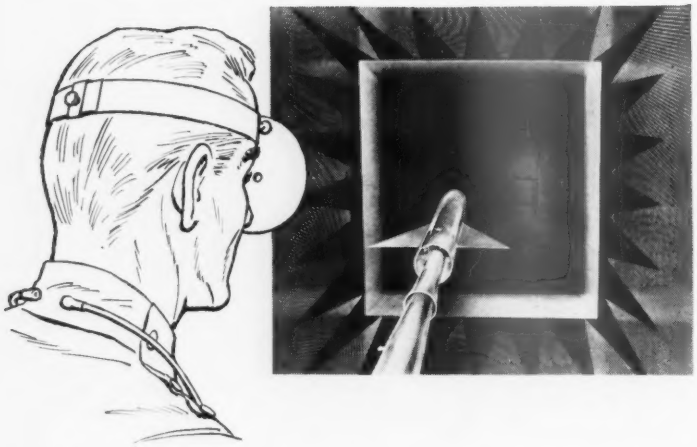

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Engineers—Fairchild Engine Division of the Fairchild Engine and Airplane Corporation, Deer Park, L.I., New York. Diversified engineering positions are available involving engine research, design, design and performance analysis, test engineering, compressor and turbine design, control systems, and other engineering operations associated with the general field of design and development of gas-turbine power plants. These opportunities result from expanded programs in a new plant and Gas Turbine Laboratory. Send résumé to Felix Gardner, Fairchild Engine Division, Deer Park, L.I., N.Y.

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The number preceding the notice represents the Box Number of the Institute of the Aeronautical Sciences to which inquiries should be addressed.

Engineers—U.S. Naval Air Turbine Test Station, Trenton, N.J., announces openings in the gas-turbine power-plant field with specialties in (a) engine performance analysis, (b) engine component (control compressor, turbine, combustion chamber, or internal flow aerodynamics) performance analysis, (c) engine testing, (d) engine instrumentation as required for evaluation of engines and their components for both steady state and transient testing, (e) facilities engineering for new facilities planning, plant expansion, and plant operation procedures. Research engineers receive "top of the grade" salaries. Specific openings are for **Supv. Aero. Power-Plant Research Engineer,** GS-834-13 ($10,065 per annum); **Aero. Power-Plant Research Engineer,** GS-834-12 ($8,645 per annum); **Supv. Mechanical Engineer,** GS-830-12 ($7,570 per annum); **Aero. Power-Plant Research Engineer**, GS-834-11 ($7,465 per annum); **Electronic Scientist** (Instrumentation), GS-1312-11 ($7,035 per annum); **General Engineer,** GS-801-11 ($7,035 per annum); **Aeronautical Power-Plant Research Engineer,** GS-834-9 ($6,250 per annum); **Mechanical Engineer,** GS-830-9 ($6,115 per annum); **General Engineer,** GS-801-9 ($6,115 per annum). Those interested are requested to apply on Standard Form 57, which may be obtained from any U.S. Post Office, or write for further information or interview to the Industrial Relations Department, Naval Air Turbine Test Station, 1440 Parkway Ave., P.O. Box 1719, Trenton, N.J.

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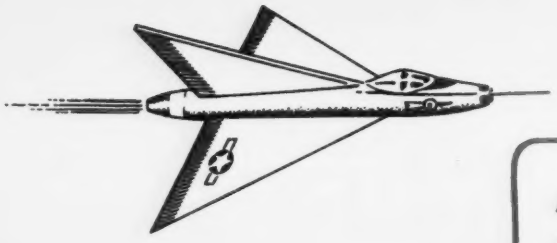

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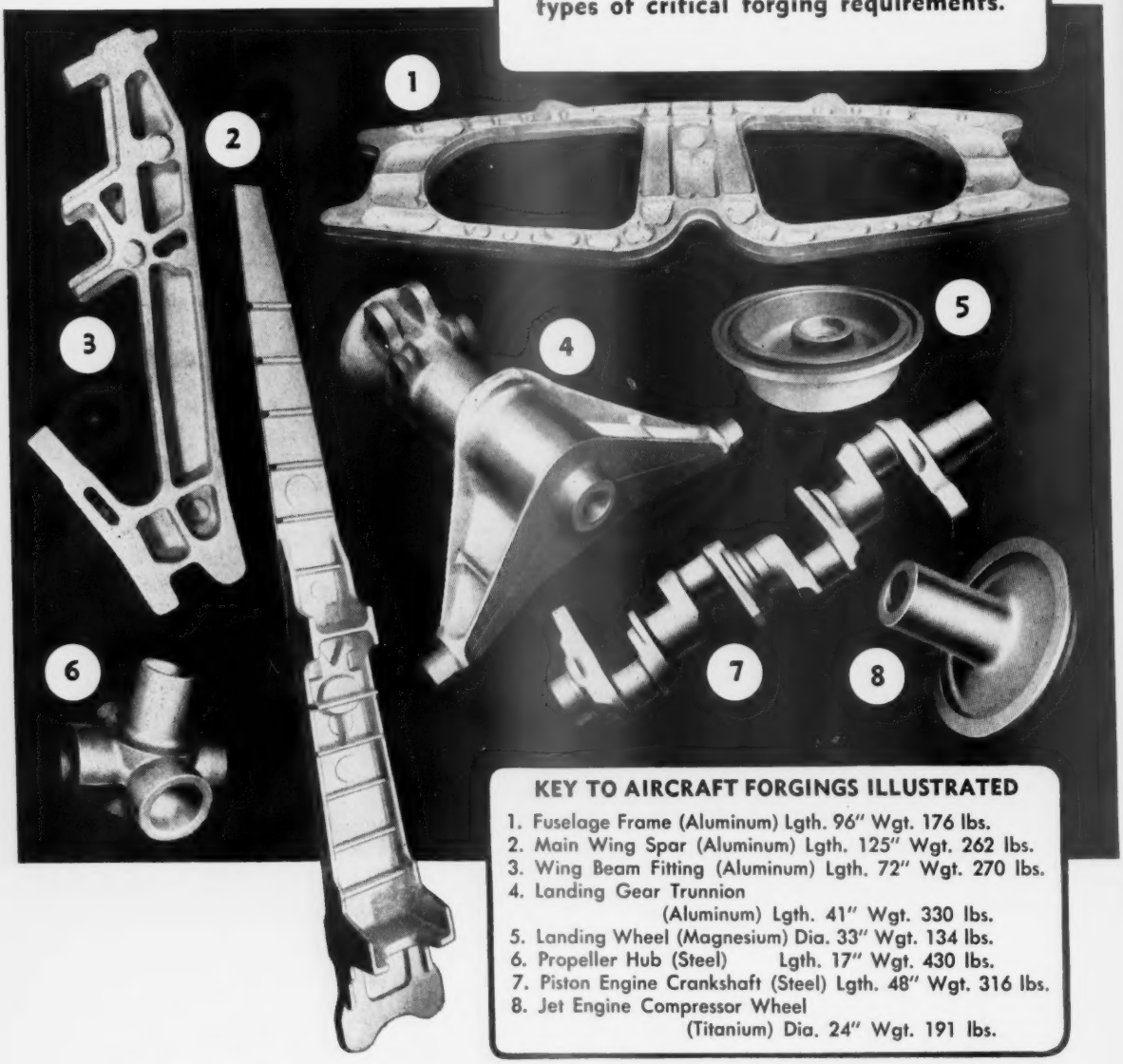

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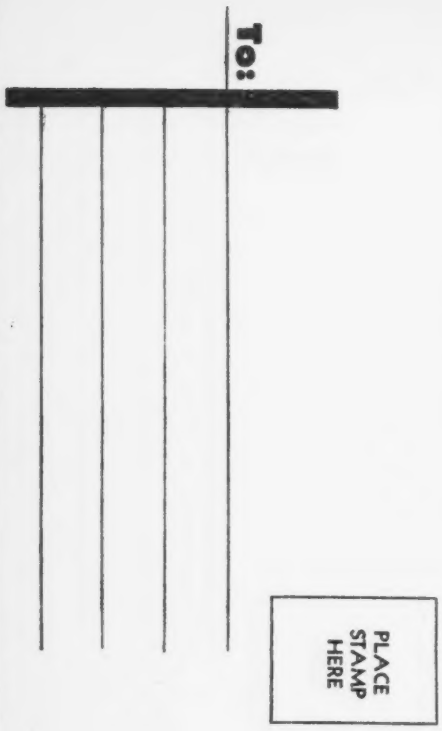

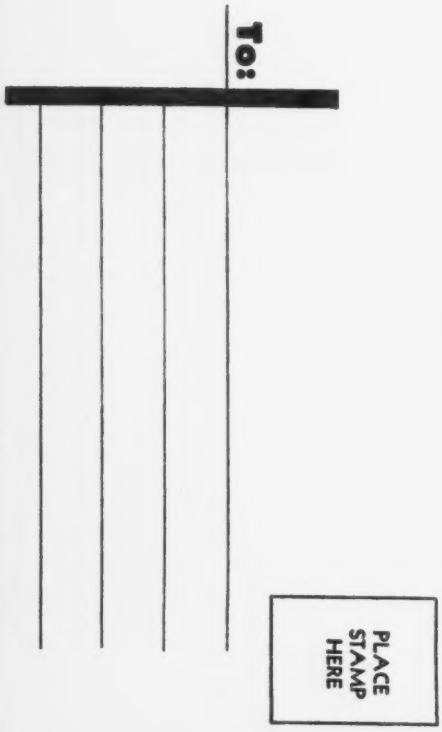

make three separate test compartments. *American Research Corp.*, Farmington, Conn.

Universal Balance Positioner. 16-page bulletin No. UB57 describes five models with capacities of 25 to 2,000 lbs. *Aronson Machine Co.*, Arcade, N.Y.

Hypersonic Shock Tubes. Tubes can be custom-made and installed to fit the requirements of purchasers. Basic tube design is made up in 5-ft. sections for installational flexibility. *Avco Mfg. Corp.*, Research & Advanced Development Div., 20 S. Union St., Lawrence, Mass.

"Tempcal" Tester. Tests accuracy of fire warning, wing anti-ice, and cylinder head temperature systems; accuracy to ±5°F. with temperatures ranging from 0° to 800°F. *B & H Instrument Co., Inc.*, Fort Worth 7, Tex.

High-Resolution Wind-Recording System. Type F is designed to give fine detail in slow-speed winds; maintains accuracies of ±4 per cent full scale of wind speed and ±3 per cent for wind direction. *Beckman & Whitley, Inc.*, 946 E. San Carlos Ave., San Carlos, Calif.

"Electroplotter S" High-Speed Automatic Plotter. Operates as a computer output by printing a complete four-dimensional graphic display in one reading. *Benson-Lehner Corp.*, 11930 W. Olympic Blvd., Los Angeles 64.

Magnetic Tape Recorder/Reproducer System. Designed to handle analog, PDM, and FM signals. May be used in wind tunnel, engine test stand, and other research studies; write for bulletin No. 1576. *Consolidated Electrodynamics Corp.*, 300 N. Sierra Madre Villa, Pasadena, Calif.

Surface-Temperature Measurement Transducer. A woven grid of fine platinum wire; claimed accurate between at least −320 and +950°F.; for use on guided missiles. *Charles Engelhard, Inc.*, 850 Passaic Ave., E. Newark, N.J.

Humidity Test Chamber. Simulates environmental conditions throughout 0° to +200°F. and 5 to 98 per cent relative humidity; better than ±2°F. control tolerance is maintained. *Environmental Equipment Co.*, 369 Linden St., Brooklyn 27.

High-Pressure Gas Booster Units. Tests all types of rocket engines; features uncontaminated boosted gas pressures up to 10,000 psi at nominal flows up to 10,000 scfh. *Greer Hydraulics, Inc.*, New York International Airport, Jamaica 30, N.Y.

AD Series High-Temperature Accelerometer Systems. These units are designed for continuous operation at temperatures up to 450°F. with no temperature compensation and no external cooling required; for missile and high-speed aircraft applications. *Gulton Industries, Inc.*, 212 Durham Ave., Metuchen, N.J.

Standard Electromechanical Breadboard Parts. 24-page catalog No. 575 contains complete descriptions on everything needed for developing servo prototypes or setting up test systems. *Helipot Technical Information Service*, Newport Beach, Calif.

Jet Aircraft & Jet-Engine Thrust Stands. Two brochures give complete technical data. *Hunter-Bristol Corp.*, Bristol, Pa.

Rocket-Powered Test Systems. 8-page brochure describes company's work in the rocket sled field. *Hunter-Bristol Corp.*, Bristol, Pa.

Monitoring Systems for Detection of Radioactivity. 6-page bulletin AM-57. *Nuclear Measurements Corp.*, 2460 N. Arlington Ave., Indianapolis 18.

Surface Pyrometer. This 1½-lb. portable instrument will check surfaces as small as 1/4 in.; accuracy is 2 per cent over the entire scale. *Pacific Transducer Corp.*, 11836 W. Pico Blvd., Los Angeles 64.

Beattie Varitron Camera for Computer Readout. Picks up readout directly from the cathode-ray tube; field-flattening optics correct distortion. *Photographic Products Inc.*, 1000 N. Olive St., Anaheim, Calif.

Miniature 1,200°C. Resistance Thermometer Probe. Provides a flat grid temperature element wound on the end of a 1-mm. tube. *Arthur C. Ruge Associates, Inc.*, 733 Concord Ave., Cambridge 38, Mass.

"Servoscope" Servosystem Analyzer. Model F measures frequencies as high as 100 cps yet affords low end coverage at 0.005 cps. *Servo Corp. of America*, 20-20 Jericho Turnpike, New Hyde Park, N.Y.

Teledyne Indicator. For indicating telemetered information from strain-gage types of transducer. *Taber Instrument Corp.*, Sect. 40, N. Tonawanda, N.Y.

Two-Channel Rectilinear Galvanometer Recorder. Bulletin No. R-502 describes "DUAL recti/riter" that records two functions rectilinearly on two full 4½-in. scales on a single chart. *Texas Instruments Inc.*, Industrial Instrumentation Div., P.O. Box 6027, Houston 6, Tex.

Air Operated Stress-Rupture & Creep Testing Machine. Amount of elongation under a prevailing load can be plotted automatically on a built-in electronic recorder; available in 12,000- or 20,000-lb. capacities. *Tinius Olsen Testing Machine Co.*, 5931 Easton Rd., Willow Grove, Pa.

All-Purpose Instrumentation Camera. Basic designs include standard instrumentation, automatic exposure control, and pulse operated interval. *Traid Corp.*, 17136 Ventura Blvd., Encino, Calif.

Programed Pulse Generator. Model 612A generates and controls a wide variety of instantly adjustable pulse programs of variable word length and word spacing with variable pulse delay time and pulse width. *Wang Laboratories, Inc.*, 37 Hurley St., Cambridge 41, Mass.

Subzero Industrial Freezers. 4-page folder illustrates six different models. *Webber Corp.*, Dept. 2B-361, P.O. Box 217, Indianapolis 6.

"Micro-Accurate" Optical Height Gage. Measures heights up to 61 in. with accuracies of ±0.000005 in. per inch of height. *Webber Gage Co.*, 12912 Triskett Rd., Cleveland 11.

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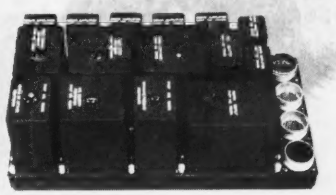

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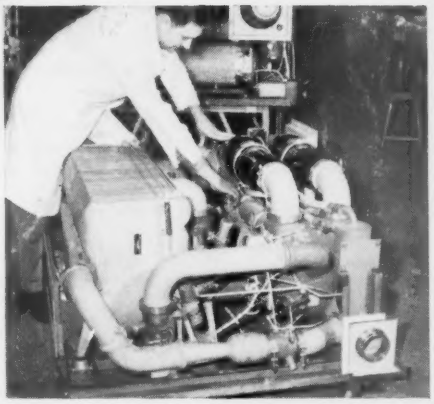

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